State of California
The Resources Agency
DEPARTMENT OF WATER RESOURCES
Northern District

SACRAMENTO VALLEY

WESTSIDE TRIBUTARY WATERSHEDS

EROSION STUDY

REEDS CREEK WATERSHED

OCTOBER 1991

Copies of this District Report are available without charge from:

State of California
DEPARTMENT OF WATER RESOURCES
P.O. Box 607
Red Bluff, CA 96080

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FOREWORD

In recent years Reeds Creek and other westside watersheds have come under increasing pressure from urbanization, livestock grazing, road building, gravel mining, agriculture, and wildfires. The reliance on wood heating has dramatically increased the harvesting and clearing of oak woodlands.

These changes have increased erosion and turbidity, affected water quality and flooding, and changed the local ecology.

The study includes maps showing geology and landslides, soils, vegetation and land use, and erosion hazards in the watershed. It documents significant changes in land use, channel morphology, turbidity, and sediment transport.

Recommendations are presented for reducing erosion, improving grazing and wildlife habitat.

Dennis Letl, Chief
Northern District

SACRAMENTO VALLEY

WETIDE TRIBUTARY WATERSHEDS

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TABLE OF CONTENTS

PART I: INTRODUCTION, SUMMARY AND CONCLUSIONS, RECOMMENDATIONS

PART II: WATERSHED CHARACTERISTICS

PART III: WATERSHED OBSERVATIONS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF PHOTOGRAPHS

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PART I: INTRODUCTION

PURPOSE AND SCOPE
PREVIOUS STUDIES
SUMMARY AND CONCLUSIONS
RECOMMENDATIONS

REEDS CREEK WATERSHED

INTRODUCTION

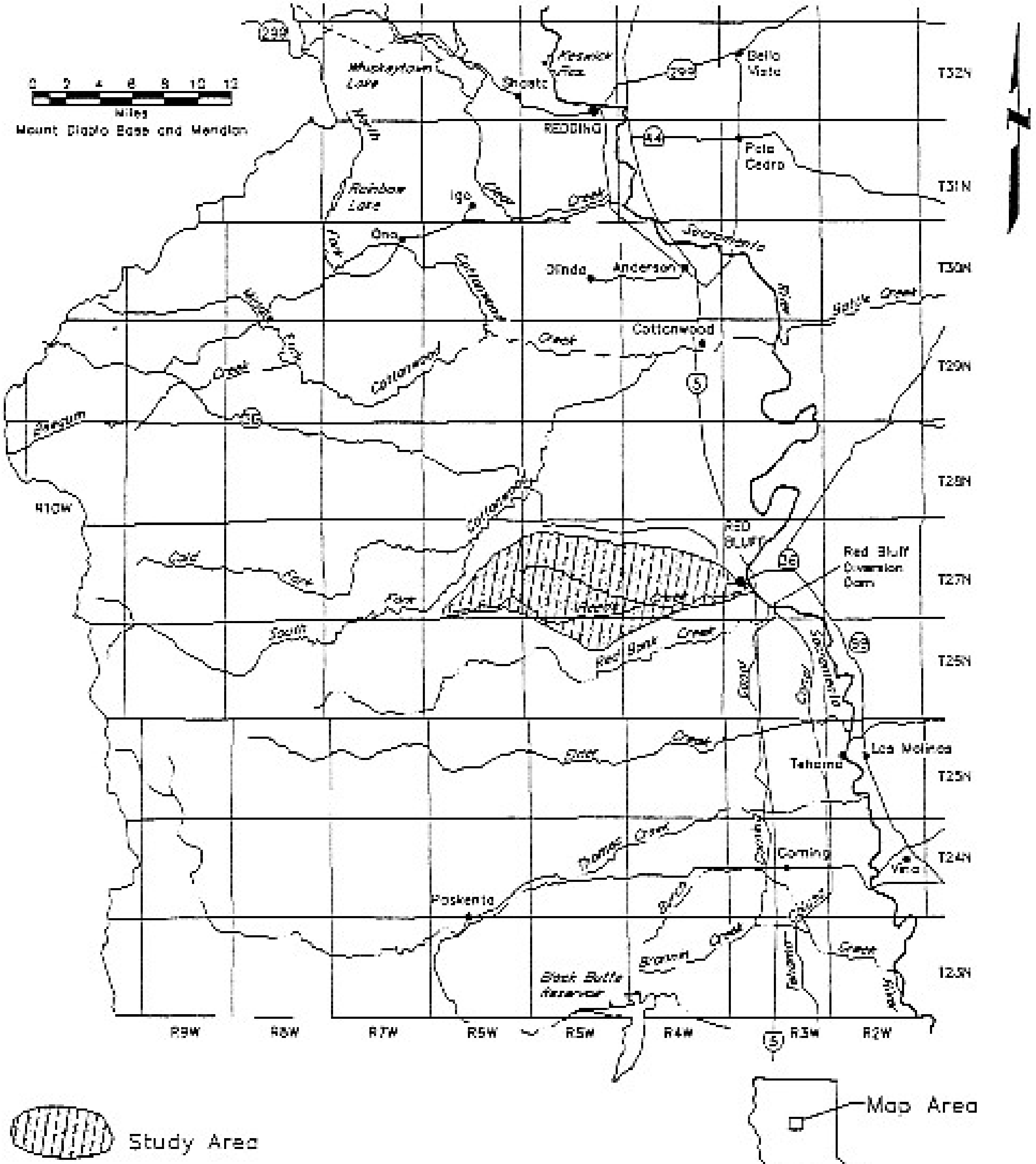
The Reeds Creek watershed lies in Tehama County directly west of Red Bluff in the northern part of the Sacramento Valley (Figure 1). It has a basin area of about 75 square miles. The creek heads in the low foothills west of Red Bluff at 1,100 feet elevation. It flows eastward for 22 miles, entering the Sacramento River two miles upstream from the Red Bluff Diversion Dam (Photo 1).

Prior to settlement by Spanish and European immigrants in the mid-1800s, this watershed was a pristine oak woodland with the natural canopy cover ranging from 10 to 100 percent. Since then, the major land uses have been livestock grazing and firewood cutting on the upland oak woodlands and limited dry land and irrigated farming on the flat valley bottoms. Between the mid-1940's and 1950's, large portions of the watershed were cleared of oak trees to improve grass cover and establish cultivated fields. In recent years, large blocks of oak woodland have been harvested to provide commercial firewood for export. Much of this cutting is occurring in the upper watershed where slopes are moderately steep. Presently 77 percent of the basin area has been clearcut. Most of the remaining area has been selectively cut. There is little oak regeneration on most of the cut-over lands. The Department of Water Resources (DWR) and numerous regulatory agencies are concerned about the possible effects this oak harvesting has on watershed erosion, forest ecology, channel stability and water quality.

Purpose and Scope

The purpose of this report is to compile and analyze the available information concerning erosion, slope stability, and water quality in the Reeds Creek Watershed. The scope of the study consisted of compiling the available data and noting the erosion occurring in the watershed.

This report is organized into three parts. PART I includes the Introduction, Summary, Conclusions and Recommendations. PART II, Watershed Characteristics, includes the geology, soils, hydrology, vegetative cover and historic land use. The geology was compiled from published mapping by the California Division of Mines and Geology (1977) and the U.S. Geological Survey (1984). The soils information is from the Tehama County Soil Survey (SCS, 1967) and was enlarged to 1:24,000 scale to match the other data. A mosaic was made from 1958, 1979, 1988 and 1990 photographs to evaluate changes in historic vegetative patterns. PART III, Watershed Observations, discusses turbidity sampling, channel changes and slope failures. An Instability and Erosion Hazard map was compiled using slope class information, observations from vertical and oblique air photos and field studies. The turbidity measurements made between 1986 and 1990



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Sacramento Valley Westside Tributary Watersheds Erosion Study
Reeds Creek Location Map

reflect the current water quality conditions and were used to identify high sediment producing areas. As-built plans at bridge sites were resurveyed to document stream channel changes. Fourteen of 27 HEC-2 cross-sections near the mouth of Reeds Creek (DWR, 1987) were also resurveyed to examine channel changes in that stream reach.

Photo 1. The confluence of Reeds Creek and the Sacramento River during the summer of 1986 was choked with sediment. The sediment stored here was the result of Lake Red Bluff backwater effects. The present operation of the dam includes raising the dam gates during winter months, allowing for the natural flushing of sediment into the Sacramento River, although a large amount of sediment still remains in the channel.

Previous Studies

The two sources of regional information available for this area are the U.S. Geological Survey's Red Bluff geologic map sheet (USGS, 1984) and the Soil Conservation Service's county soils descriptions (SCS, 1967). Site specific reports include the U.S. Bureau of Reclamation's investigation of the backwater effects of the Red Bluff Diversion Dam on lower Reeds Creek (USBR, 1970, 1985). In January, March, and December 1983, flooding along the stream initiated the "Reeds Creek Flood Study" (DWR, 1987). That study included 27 cross-sections along the lower mile of the stream. DWR installed a stream gage 2.5 miles upstream from the mouth to monitor discharge. Data have been collected at that site since 1984. The only other site-specific technical information available are a foundation report for a proposed bridge on Paskenta Road (Hill-Harned & Assoc., 1973) and Caltrans and the Tehama County Road Department as-built plans for seven bridge crossings.

SUMMARY AND CONCLUSIONS

Reeds Creek is in the northwestern part of the Sacramento Valley, in Tehama County, California. The 75.2 square-mile basin drains an area that has been extensively altered by human activities, including urbanization, dry land farming, grazing and oak woodland harvesting. Some of the impacts of these changes include increased erosion, turbidity and sedimentation, reduced water quality, and destruction of oak woodland habitat.

DWR began this study by compiling the geology, soils, vegetation and land use maps. We then made a detailed watershed reconnaissance to map erosion sites and landslides. Turbidity samples were collected during high flow events.

Geologic and soils units were rated according to landslide and erosion susceptibility. An "Instability and Erosion Hazard" map (Plate 4) shows the unstable and erodible areas of the watershed.

The following are conclusions resulting from the investigation:

1. Seventy-five percent of Reeds Creek basin is underlain by the Tehama Formation. In the watershed, the Tehama consists mostly of moderately consolidated clay and silt with minor sand and gravel lenses. The formation underlies low relief hills and broad ridge tops that have a moderate erosion hazard. Steeper areas are susceptible to rill and gully erosion and have a high erosion hazard. Because of the predominance of fine-grained material, storm runoff from eroding areas are typically highly turbid.

2. Most of the remaining basin is underlain by Quaternary to Recent stream terraces and Recent alluvium in flat stream valleys that have a low erosion hazard. Most of the erosion and sediment yield from these units are from near-vertical stream banks cut into the terraces.

3. After the mid-1940s, about one-half of the watershed was converted from oak woodland to open grassland for grazing. Since then, open grassland acreage has increased to about 77 percent of the basin. An additional 3 percent has been urbanized. Oak woodland has decreased from an estimated 90 percent of the basin before settlement by Europeans, to about 53 percent in 1958, and to 20 percent in 1990. This has resulted in a major loss in wildlife habitat.

4. Reeds Creek stream turbidities are abnormally high during winter stormflows. It is clear that grazing, oak harvesting and road building have increased stream turbidities, sediment yield and peak discharges over historic levels. However, there are no recorded data to show how much. Turbidity and suspended load will continue to increase in response to heavy and/or prolonged rainfall and poor land use practices.

5. The soils can be divided into three slope classes that, along with gully density, landslides and

geology, define the relative erosion hazard rating for the basin (see Plate 4). The major types of erosional processes in this basin are probably rill and gully erosion with some sheet erosion (SCS, 1979). A few landslides occur. Accelerated erosion occurs as rills and gullies in overgrazed areas, as rilling on unvegetated road and stream bank cuts, and as gullying downslope of road drainage ditches.

6. The National Weather Service maintained hourly precipitation information at the Red Bluff airport, just south of the watershed, until 1987. Some of that record was coincident with data gathered at the Wilder Stream gage. These data were used to compile the unit hydrograph (Figure 6). Flooding in response to intense rainfall is common in the creek's lower five miles. Peak runoff is increased because of the relatively impervious soils underlying most of the basin. The flooding is exacerbated by the equivalent length of the three major tributaries-- Liza, Reeds, and Pine Creeks-- resulting in the arrival simultaneous flood peaks in the lower basin.

7. One predictable effect of the intense grazing, compaction and vegetation removal is a higher peak discharge.

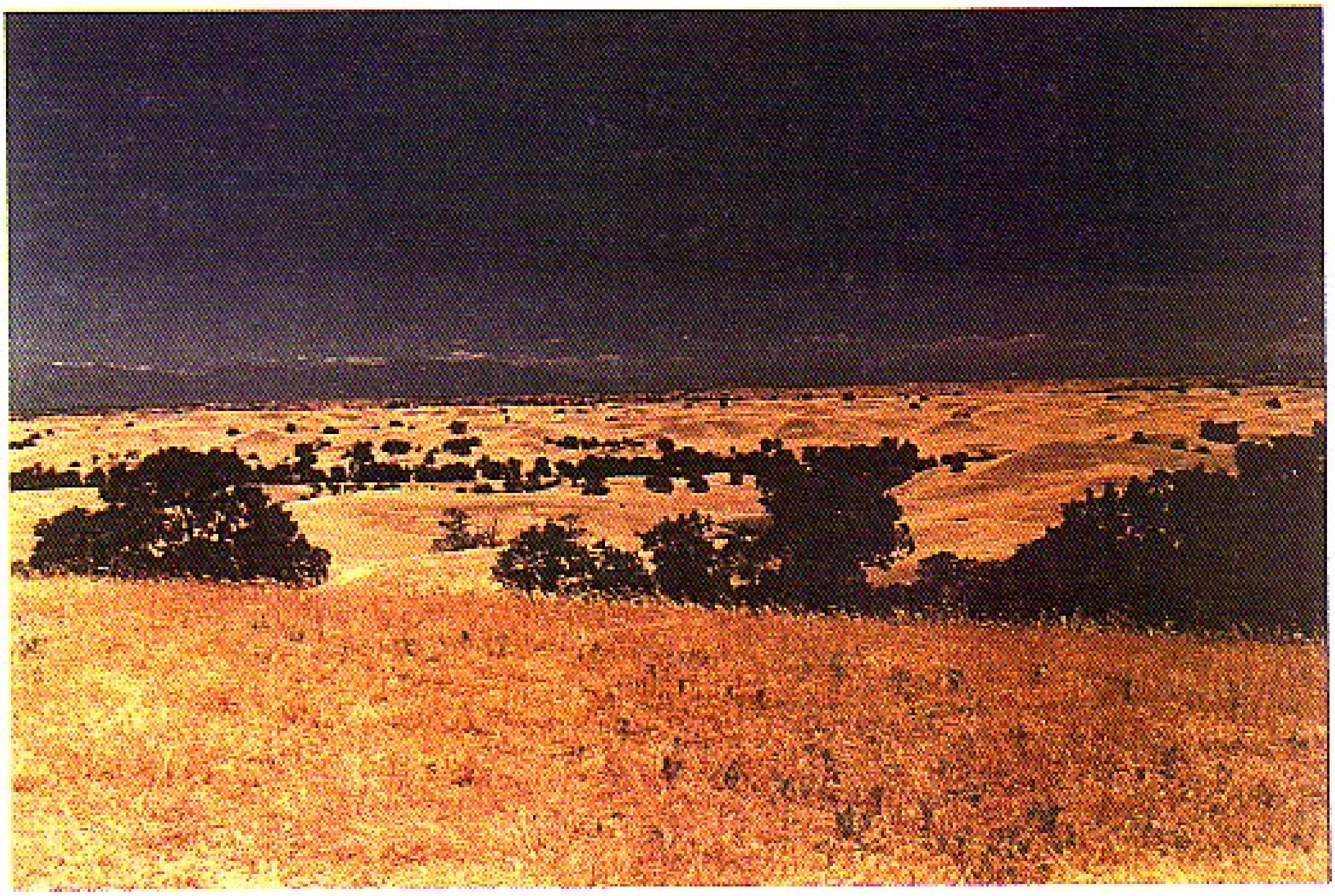


Photo 2. Seventy seven percent of the basin has been clearcut leaving only scattered blue oaks.

RECOMMENDATIONS

Recommendations are divided into range management and erosion control categories. These recommendations are general, are not intended to be all-inclusive, and are not applicable to all situations.

Range Management

There are numerous new ideas and methods for dealing with oak woodland range management (Mark Parsons, U.S. Soil Conservation Service, Personal Communication). Land managers tend to agree that wholesale removal of oak from rangeland is a poor management practice. The number of leave trees recommended for oak woodland to grassland conversions are now considerably higher than in the past. Oak canopy cover of 30-50 percent is an ideal compromise between range and wildlife benefits. Deer, quail, squirrel, wild turkey, feral pigs and a host of others consume acorns and use oak habitat. We now recognize the wildlife benefits of oaks for nesting, as a food source from the acorns and oak leaf browse, and for shade. About half of the acorns are consumed by range animals, providing a valuable feed supplement to cattle and sheep.

There is also some controversy regarding the removal of oaks from the drier, less fertile sites. Some range managers believe that oak removal in these cases will actually decrease forage production, since soil richness and moisture holding capacity is generally higher under the trees in these soil types. Research has also shown that the increased forage production on cleared lands drops off or disappears after about 15 to 20 years. DWR recommends further research in the northern Sacramento Valley on this subject.

The U.S. Soil Conservation Service now recommends a "Holistic Range Management" approach (Mark Parsons, Personal Communication). This approach includes managing for multiple resource values, such as range, oak firewood production and wildlife. Grazing is controlled using cross-fencing. This allows the owner to uniformly graze the range while providing adequate rest to prevent overgrazing. Fencing to exclude livestock is also recommended for sensitive riparian areas or rilled and gullied eroding areas. The approach also recommends adequate residue to reduce erosion. Livestock should be removed from open range by the end of April or sooner. Soil compaction should be carefully monitored. Compaction will reduce soil productivity and increase runoff and downslope erosion. The stock that remains in the valley during the summer should be placed in feedlots, permanent pasture or paddocks to prevent excessive range damage.

Erosion Control

A number of the above rangeland management methods are effective for erosion control. These include selective fencing, residue management and controlled grazing. Stock should be dispersed by providing water away from riparian areas. Trees should be left in gullies and on steep sideslopes when converting oak woodland to grassland. Dryland farming, particularly discing, should be confined to flat areas such as floodplains and terraces.

Roads in the basin are a serious source of sediment. Erosion control methods will vary depending on the type and use of the road. Seasonal roads should be outsloped and provided with rolling dips to prevent concentration of runoff. Surfacing should be provided whenever possible. Roads should be built when soil moisture is at an optimum for road compaction. Cuts and fills should be mulched and reseeded. Unstable and erodible ground should be avoided, and, whenever possible, sideslopes should be avoided by placing roads on ridges and in valleys. Maintenance, particularly of drainage control devices, is important. Drainage should be diverted and dissipated in sensitive areas. Riprap should be placed in downdrains and eroding gullies below concentrated runoff.

PART II: WATERSHED CHARACTERISTICS

GEOLOGY
SOILS
HYDROLOGY
VEGETATIVE COVER
HISTORIC LAND USE

GEOLOGY

Reeds Creek lies within the Sacramento Valley, in the Great Valley Geomorphic province. The province extends throughout the Great Central Valley of California. Most of the rocks and deposits are sedimentary, ranging in age from Upper Jurassic to Recent.

The Great Valley province is a 400-mile-long by 60-mile-wide sedimentary basin between the granitic and metamorphic terrane of the Sierra Nevada and the metamorphic Coast Ranges. The basal rocks are Upper Jurassic to Upper Cretaceous marine sandstone, shale and conglomerate of the Great Valley Sequence. The Great Valley Sequence was deposited in the western continental forearc basin during the Middle to Late Mesozoic. Younger deposits consist of sedimentary and volcanic deposits of Tertiary and Quaternary age, such as the Tehama Formation, the Nomlaki Tuff member and the Red Bluff Formation. Quaternary alluvium, terrace and landslide deposits cap the sequence.

Structurally, the Great Valley Sequence is an asymmetric southerly plunging syncline, with a steeply dipping western limb and a gently dipping eastern limb. Along the west side of the valley, the Great Valley Sequence has been uplifted to form a series of northwest-trending, steeply eastward dipping ridges.

The geomorphic provinces surrounding the Great Valley include the Coast Ranges, Klamath Mountains, Cascade Range, and Sierra Nevada.

West of the basin, the Coast Ranges province consists of rocks and structures ranging in age from Jurassic to Tertiary. Together, the graywacke, metagraywacke, shale, chert, limestone, mafic and ultramafic rocks make up the Franciscan complex. The Franciscan complex is commonly characterized by zones of extensive shearing, folding, faulting and the presence of ophiolite/serpentinite melanges.

Along the eastern flank of the Coast Ranges, the Franciscan complex rests structurally beneath, and/or faulted against, a fragmental assemblage of ultramafic rocks. This sequence of units, called the Coast Range ophiolite, consists of middle to late Jurassic oceanic crust and upper mantle. One of the more complete ophiolites occur about 10 miles south of the basin along South Fork Elder Creek (Suchecki, 1984). North from Elder Creek, the Coast Range ophiolite narrows and then terminates. The Coast Range ophiolite forms the basement beneath the sedimentary rocks of the Great Valley Sequence.

Northwest of the basin, the Klamath Mountains province ranges in age from Paleozoic to Jurassic. It consists of several well-defined mountain ranges, including the Trinity, Marble, Scott, Trinity Alps and Salmon mountains. These mountains comprise a series of northwest-trending metamorphic terranes separated by major faults. Each terrane differs in age, stratigraphy, and tectonic deformation. Large bodies of intrusive rocks occur throughout the province.

Most of the dominant structural features in the Klamath province can be related to Pre-Cretaceous subduction. The exact sequence and timing of the Pre-Cretaceous subduction is still unclear, but it is postulated that subduction occurred during a later episode of the Nevadan Orogeny, which was responsible for much of the Sierra Nevada deformation (Ingersoll, 1986). Faults along the margins of the Klamath terranes most likely represent old subduction zones where two crustal plates, or parts of a broken plate, converged to create the separate and distinct terranes.

Northeast of the basin, the Cascade Range is a 500-mile sequence of volcanoes extending from Mount Lassen to Mount Garibaldi in British Columbia. Rocks of the California Cascade Range are predominately volcanic rocks of great variety and form. In northern California, Upper Cretaceous and Eocene sedimentary rocks are at the base of the sequence. These are overlapped by Upper Eocene volcanic rocks of the Western Cascade series and Quaternary-Tertiary pyroclastic rocks and flows. Northwest of Mount Lassen the Upper Pliocene Tuscan Formation rest directly on Cretaceous and Eocene sedimentary rocks.

Tectonically, the Cascade volcanoes are the product of the active subduction of the Gorda plate (California), and the Juan de Fuca or "Cascadia" plate (Oregon) beneath the North American plate. Since the deposition of the Nomlaki Tuff member of the Tehama Formation (3.4 mybp), volcanic activity has occurred intermittently along the southern Cascade Range (Harwood, 1987).

The Sierra Nevada lies to the east, is about 400 miles long, and ends to the north near Lassen Peak. The rocks of the province are of diverse composition and age, but consist mostly of igneous and metamorphic units. Structurally and tectonically, the Sierra Nevada region is very complex. Some structural deformation dates back 300 million years or more, and is attributed to Paleozoic and Mesozoic subduction.

Geologic Units

Plate 1 shows the geology of the Reeds Creek watershed. The Tehama Formation is the major geologic unit that underlies the watershed. This formation is semi-consolidated and typically fine-grained. These two characteristics influence the general topography and largely determine the natural erosion rates.

Table 1 shows the percentage of each geologic unit in the basin. The predominant surficial unit is the Tehama Formation underlying 77 percent of the basin. Terrace deposits underlie an additional 22 percent, and Alluvium about 1 percent. The Nomlaki member of the Tehama Formation (Tm), Great Valley Sequence mudstone (Kms), and landslides (Qls) make up less than 1 percent of the basin.

Great Valley Sequence

The Great Valley Sequence (GVS) crops out in one small area near the upper end of the basin. Extensive exposures occur along the Sacramento Valley's west side. Here the sequence consists of interbedded sandstone, conglomerate, and mudstone. The bedding dips east and strikes northwest, forming long linear ridges and valleys.

TABLE 1
Areas and Percentages of Geologic Units

Geologic Unit	Basin Area (sq. miles)	Basin Percentage
Great Valley Sequence(GVS)	<0.1	<0.1
Tehama Formation (Tte)	57.9	77
Nomlaki member (Ttn)	<0.1	<0.1
Red Bluff Formation (Qrb)	2.3	3
Upper Riverbank Fm (Qru)	9.0	12
Lower Riverbank Fm (Qrl)	2.2	3
Upper Modesto Fm (Qmu)	0.8	1
Lower Modesto Fm (Qml)	2.2	3
Quaternary Alluvium (Qal)	0.8	1
Landslides	<0.1	<0.1
Total	75.2	100

In the Reeds Creek watershed a small outcrop of GVS Cretaceous mudstone (Kms) has been exposed by erosion of the overlying Tehama Formation. This outcrop was not studied since it represents such a minor percentage (<0.1 percent) of the basin area.

Tehama Formation

The Plio-Pleistocene Tehama Formation (Tte) underlies 77 percent of the watershed. Regionally, the Tehama Formation is composed of fluvial sedimentary deposits of semi-consolidated pale-green, gray and tan sand, tuffaceous sand, silt, and clay. The formation has scattered, discontinuous lenses of gravel. The clast lithologies indicate that they were derived from the Coast

Ranges and Klamath Mountains to the west and northwest (Russell, 1931). The formation has a low regional dip towards the east and the Sacramento River. The Tehama becomes finer away from the mountains of origin. Photo three shows a typical exposure of the Tehama Formation. In general, the Tehama Formation forms rounded hills with moderate relief and has a thin soil cover. Along streams, exposures form 20- to 60-foot high vertical bluffs. Cutbanks with 1:1 and steeper slopes are normally stable but erodible.

Numerous outcrops of Tehama Formation were examined throughout the basin. Exposures consist of tan- to buff-colored semi-consolidated sand, silt and clay occurring as massive units ranging from 5 to 40 feet thick. Sparse gravel lenses with a clayey or silty matrix occur. The overall appearance of the Tehama Formation is typically fine-grained.

Soil erodibility depends on composition. Predominantly silt outcrops are more erodible than sand or clay. Silt does not have the cohesion typical of clay, or the permeability typical of sand. Extensive gullying occur in parts of Brickyard Creek underlain by silt.

The minor gravel lenses do not appear to affect the general erodibility or slope stability.

Nomlaki Tuff Member. The Nomlaki Tuff Member (Ttn) is a Pliocene, white to light-gray dacite pumice tuff and lapilli tuff that occurs near the base of the Tehama Formation. The bedding probably conforms with the shallow eastward dip of the Tehama Formation. The member is a massive, non-layered volcanic ash that forms resistant vertical banks along streams and gullies. Maximum thickness is approximately 30 feet. In the upper watershed there are two small outcrops, comprising less than 0.1 percent of the basin.

Red Bluff Formation

The Pleistocene Red Bluff Formation (Qrb) makes up three percent of the watershed. Regionally, the Red Bluff Formation is a coarse gravel deposit with a brick-red clayey matrix. This formation originally formed on a regional gently inclined erosional surface, or pediment, on the Tehama Formation. Erosional remnants of the Red Bluff crop out along the western headwaters, along the ridge that forms the southern boundary of the watershed and in the city of Red Bluff.

Along Ridge Road, the Red Bluff Formation consists of gravel with a reddish clayey matrix. The low areas in places contain either more recent deposits or the underlying Tehama Formation. These have not been differentiated. To the east along Live Oak Road, the color is redder. Most of the coarse fraction is gravel-sized with a few larger clasts. Hardpan occurs locally.

In the City of Red Bluff and in the Brickyard Creek basin, the formation may be as thick as 30 feet and contains larger clasts than elsewhere in the watershed.

Terrace Deposits

Reeds Creek and its major tributaries have developed a set of terrace levels flanking the stream channels. These terraces stair-step in elevation away from the active channel, with the upper terraces the oldest.

Terrace deposits are typically complexly intertwined, and each mapped terrace may have several minor deposits of different age and elevation associated with it. These are typically not differentiated.

The four Pleistocene terraces that occur in the watershed are the Upper Riverbank, Lower Riverbank, Upper Modesto and Lower Modesto. These terraces have been correlated by their absolute age, soil stratigraphy, geomorphic expression to the Riverbank and Modesto Formations of the San Joaquin Valley (USGS, 1984).

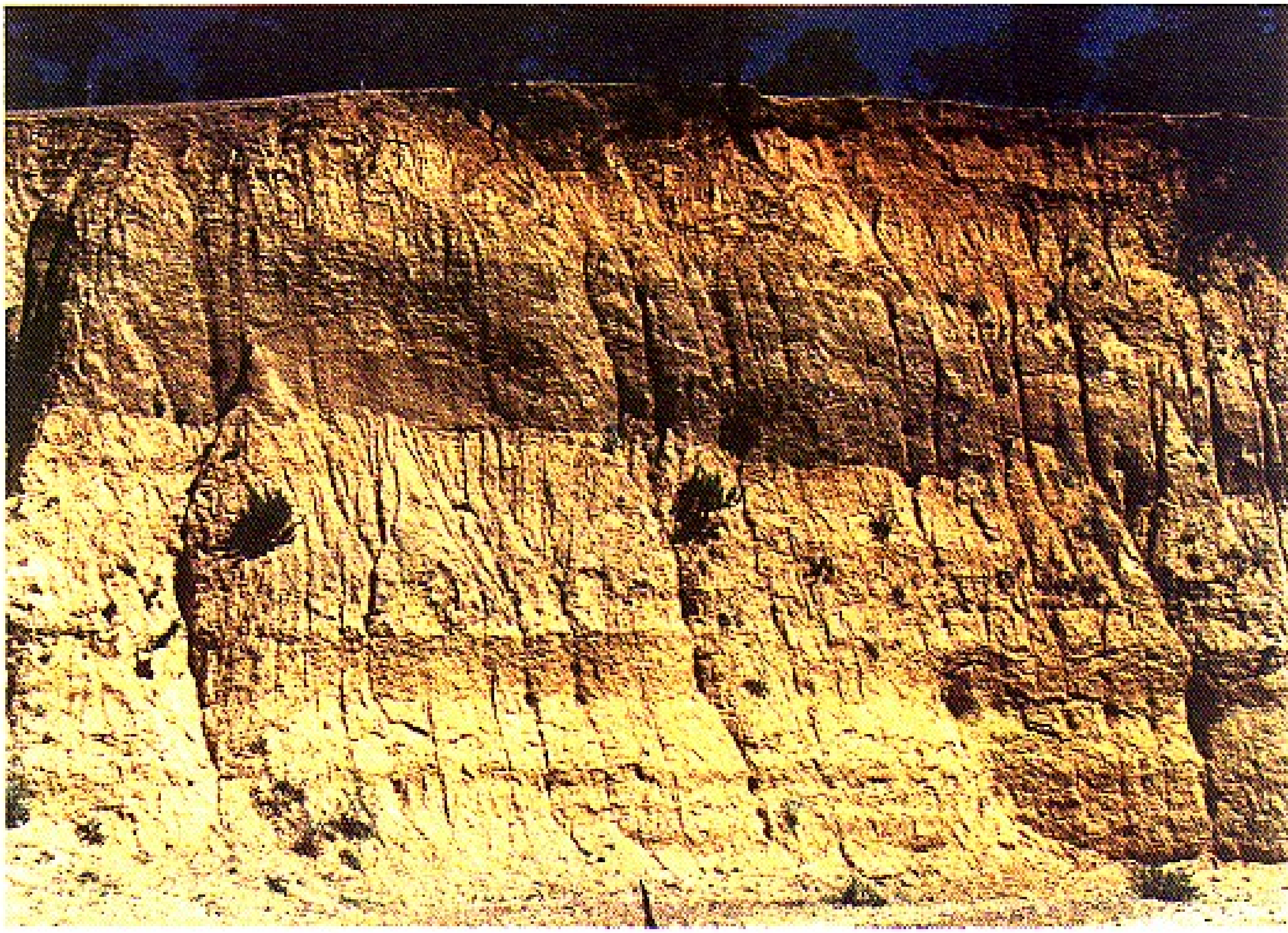


Photo 3. The fine-grained sedimentary deposits of the Tehama Formation are well exposed along Pine Creek.

Riverbank Formation. The Pleistocene Riverbank Formation has been divided into an upper and lower member. The lower member (Qrl) is lithologically similar to the Red Bluff Formation and has nearly the same red color. It consists of gravel, sand, silt and clay. It occurs on the higher of two flat terraces that have been cut and filled into the surface of the Red Bluff and/or Tehama Formations and comprises 3 percent of the watershed.

The upper member (Qru) is the youngest and comprises 12 percent of the watershed area. It formed during a long period of stable climatic conditions. This member occurs as extensive flat stream terraces along the major tributaries of Reeds Creek. A typical outcrop consists of 8-10 feet of tan to light brown sandy silt underlain by 1-3 feet of gravel and scattered rocks up to eight inches in diameter. Soils of the member display medial development with strong textures. The soil contains a B-horizon and local hardpan but profile development is not as great as on the lower member.

Modesto Formation. The Modesto Formation has also been divided into an upper and lower member. The lower member (Qml) is the youngest terrace that has a pedogenic B-horizon. Terraces display fresh depositional morphology with few erosional features. The formation occurs in the upper reaches of some of the tributaries and is found stair-stepped below the Riverbank Formation along the lower reaches of Reeds Creek.

The Upper Modesto (Qmu) does not have a soil horizon. This unit borders existing channels and is generally less than 10 feet thick. It is composed of gravel, sand, silt, and clay and comprises about one percent of the watershed area.

Surficial Deposits

Surficial deposits in the Reeds Creek watershed include Quaternary alluvium and landslides. Together, these two units make up less that one percent of the basin.

Alluvium. The Quaternary alluvium (Qal) occurs in the active stream channel. The only place this deposit has appreciable depth and width is in Burr Valley and along the lower 2-3 miles of the creek. Alluvium occurs as loose, unconsolidated sand and gravel in the active stream channel and as sand, silt and clay with minor lenses of gravel on the flood plain adjacent to the active channel.

Landslides. Mappable landslides are rare in the Reeds Creek watershed. Analysis of 1988 aerial photographs revealed no large-scale slope failures or landslide deposits. Field surveys and analysis of 35mm color slides flown at 3,000 and 6,000 feet show that scattered, small-scale landslides occur, mostly near the crests of ridges above elevation 700 feet where the relief is steeper. These landforms have been plotted with the larger areas of actively eroding headcuts. One area on the north side of Brickyard Creek contains several large earthflows (Photo 5).

Photo 4. Upper Riverbank Terrace deposits such as this terrace in Burr Valley, are common.

Geologic Structure

The main geologic structure in the watershed is the slight eastward dip of the Tehama Formation. The Tehama is underlain unconformably by Great Valley Sequence rocks that dip steeply to the east.

The Red Bluff Fault is a subsurface feature that extends northeast and southwest from Red Bluff. The location in the Reeds Creek basin is taken from Harwood and Helley (USGS,1987) and is based upon proprietary subsurface data. They report that there are no surface features that can be associated unequivocally with the fault even though there may be as much as 450 feet of subsurface vertical offset, south side down.

Tectonic Setting

The Reeds Creek basin is in the northwestern part of the Sacramento Valley in the Great Valley Geomorphic province. This province includes a thick sequence of marine and continental sedimentary rocks in a large, elongated northwest-trending structural trough. The trough is floored with basaltic and ultramafic oceanic crust and mantle. Age of the deposits range from Jurassic to Recent. The trough is a region of relative tectonic stability that has persisted in approximately its present structural form throughout most of Cenozoic time.

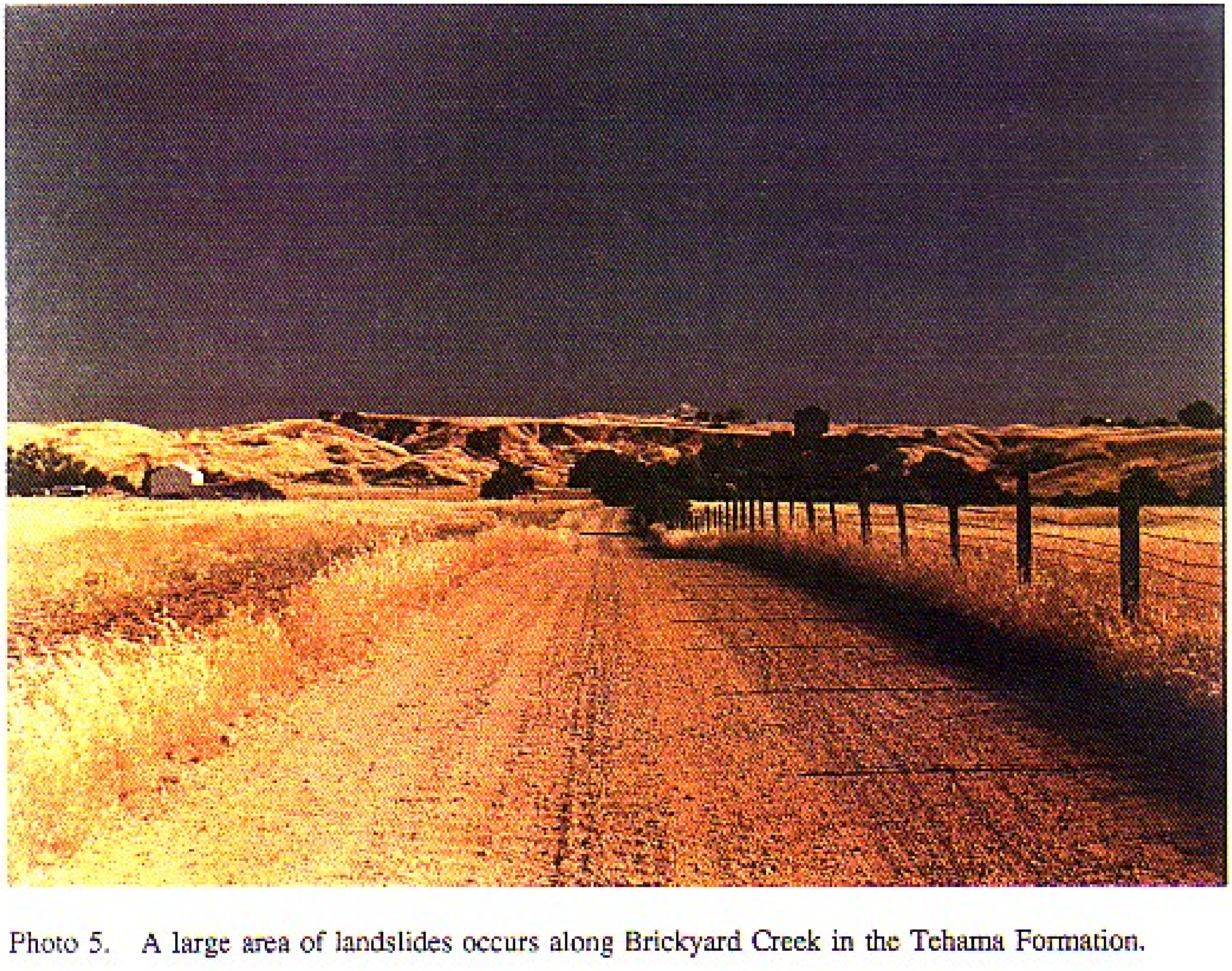


Photo 5. A large area of landslides occurs along Brickyard Creek in the Tehama Formation.

Plate tectonics have played a major role in the tectonic development of California. From late Jurassic to mid-Tertiary, the eastern Pacific oceanic lithosphere (Farallon plate) was subducted

beneath the western margin of the North American continental plate. This subduction resulted in the formation of an arc-trench system that included an accretionary prism, a forearc basin, and a volcanic-plutonic magmatic arc. Today these terranes are represented by the Franciscan complex, the Great Valley Sequence, and the Klamath and Sierran plutonic/metamorphic belt.
Throughout Cretaceous time, rocks eroding from the surrounding plutonic and metamorphic belts were deposited by submarine turbidity currents into the deep forearc basin. These sediments, the Great Valley Sequence, continued to accumulate, filling the forearc basin to near sea level by Paleogene. During this same period, ocean floor and trench deposits of the Franciscan complex were being dragged down by the Pacific plate, and underthrust in a wedge against the continental margin and beneath the Great Valley sediments (Ingersoll, 1983). As more oceanic material were deposited beneath the continental plate, the accretionary wedge increased in size. Subsequent underthrusting resulted in the sediments of the forearc basin to be uplifted and tilted to the south and east (Harwood and Helley, 1987).

Marine deposition and subduction of the eastern Pacific oceanic lithosphere beneath mainland California continued through Oligocene time. As subduction ceased during mid-Tertiary, uplift became more rapid and the transition to a strike-slip regime began offshore in southern California. This transition led to the formation of the San Andreas transform fault.

As the San Andreas fault evolved, a triple junction between the Pacific-Farallon, North American, and Gorda lithospheric plates began to develop and migrate slowly northward. During this period, the Great Valley experienced several episodes of uplift and subsidence, until by early Miocene, most of the northern valley had emerged from the inland seas and was subjected to fluvial erosion and deposition (Hardwood, 1984). Concurrently, volcanic eruptions were occurring along the northern Sierra Nevada, damming streams and filling narrow valleys.

At about the same time, extensional forces from behind-the-arc spreading east of the Sierra Nevada reached their peak. These forces are responsible for the rapid uplift of the Sierra Nevada.

By early Pliocene, the Mendocino Triple junction had migrated north approximately to Point Arena. Evidence suggests that as the triple junction continued to move northward offshore, structures in the valley began to simultaneously exhibit compressive deformation along a similar northward-progressive pattern (Harwood, 1984). Beginning with activity at the Sutter Buttes (2.5 mya) and continuing to the recent activity in Battle Creek Fault region (0.5 mya), the progressive northward pattern of valley deformation correlates with the latitudinal positioning and late Cenozoic movement of the Mendocino triple junction.

Presently, the Gorda plate is subducting beneath the North American plate. Activity associated with this movement can be seen in the surface folding, faulting and uplift of the northern Coast Range, and in the 152-mile long zone of intermediate-focus earthquakes dipping eastward below the North American plate. Beneath the basin, several intermediate and deep-focus microseismic events correlate with the Gorda plate subduction (Cockerham, 1984; Walter, 1986).

Presently, the northern Sacramento Valley lies between the large-scale right-lateral transform tectonism of the San Andreas fault to the west, and the major east-west crustal extension of the northern Basin and Range province to the east. The current state of compressional stress is a result of regional forces manifesting their stress regime upon the valley, rather than localized forces originating within the valley. The direction of stress may vary locally, but in general, the direction of maximum compressive stress is approximately northeast-southwest.

Evidence of this stress regime manifest itself as a series of northwest trending folds and faults along the western Sacramento Valley. The faults dip steeply east, with reverse and minor left-lateral movement. In the north and northeastern valley, the structural trend shifts and, folds and faults become oriented in a more east-to-northeasterly direction. These faults typically dip steeply to the south, with normal offset and minor right-lateral movement.

Recent studies suggest that uplift along folds paralleling the western valley is active, and may represent the shallow expression of deeper thrusting. Interpretation of seismic reflection data (Unruh, 1990) indicates that these folds are due to active thrusting along a very large triangular wedge of rocks. This imbricate zone of detachment faults may represent the boundary between the rocks of the Coast Ranges, Great Valley, and Sierra Nevada. Additional evidence presented by Wong (1988), Stein (1989) and Wentworth (1990), suggests that this zone of faulting (commonly referred to as the Coast Ranges-Sierran Block boundary zone) extends the full length of the western valley and is most likely responsible for the two 1982 Winters/Vacaville earthquakes (ML 6-7) and the 1983 Colinga earthquake (ML 6.7).

The Great Valley Sequence rocks were deposited in a subsiding continental forearc basin during the middle to late Mesozoic. By the Pliocene, these rocks had been regionally tilted and had gone through several cycles of uplift and erosion. During the Pliocene, continental sediments of the Tehama Formation were deposited as large coalescing alluvial fans over the GVS sedimentary rocks at the foot of the emerging Coast Ranges. The Nomlaki Tuff Member, which occurs locally at or near the base of the Tehama is an ash fall from volcanic eruptions that blanketed much of the northern valley about 3.4 million years ago.

Eventually the Tehama Formation covered the GVS with sediments to a depth of 0-2500 feet on the eroded surface of the tilted GVS rocks (ESA, 1980). Subsequent erosion and redeposition have formed the outcrop patterns of geologic units. Fluvial processes have formed the terrace and alluvial deposits as they appear today.

SOILS

Soil is a thin layer that forms on the earth's surface as a result of five soil-forming factors: climate, relief, organic content, parent material, and time. Soil is the main storehouse for plant nutrients, the essential medium of plant growth, a major repository of water, and the physical support for plants. The health of the soil in large part determines the health and vitality of the vegetation it can support. In the Reeds Creek watershed, the health of the soil and vegetation is the first line of defense against soil detachment and erosion.

Soils Units

Plate 2 shows the areal distribution of soils and lists the slope and capability class of each soil unit. The soils mapping was done by the U.S. Department of Agriculture, Soil Conservation Service (SCS, 1967) on aerial photographs. Each soil shown on this map is either a soil series or a soil complex. The soils of a soil series have the same thickness and major subsurface horizons. A soil complex is a collection of soil types too intricately mixed or too small to map separately. They are designated by a hyphenated name, such as the Nacimiento-Newville Complex.

The soils are classified further using slope and capability classifications. The slope is determined by field survey and aerial photographic interpretation. The capability classification shows, in a general way, the suitability and limitations of the soil groups for farming.

In the capability system, the nature of a soil is described at three levels; the capability class, the subclass, and the unit. These three are discussed in the following paragraphs.

Capability classes, the broadest grouping, are designated by Roman numerals I through VIII. These numerals indicate progressively greater limitations for practical use in farming and are defined as follows:

Class I soils have few limitations that restrict their use.

Class II soils have moderate limitations or require moderate conservation practices.

Class III soils have severe limitations, require special conservation practices, or both.

Class IV soils have very severe limitations, require very careful management, or both.

Class V soils are subject to little or no erosion but have other limitations, impractical to remove, that limit their use largely to pasture, range woodland, or wildlife habitat.

Class VI soils have severe limitations that make them generally unsuited to cultivation and limit their use largely to pasture, range, woodland, or wildlife habitat.

Class VII soils have very severe limitations that make them unsuited to cultivation and that restrict their use largely to pasture, range, woodland, or wildlife habitat.

Class VIII soils and landforms have limitations that preclude their use for commercial plants and restrict their use to recreation, wildlife habitat, or water supply, or to esthetic purposes.

Capability subclasses are used to indicate additional information within one of the classes above. They are designated by adding a small case letter *e*, *w*, *s*, or *c*, to the class number and are defined as follows:

e shows the main limitation is a risk of erosion unless close-growing plant cover is maintained.

w shows that water in or on the soil surface interferes with vegetative growth.

s shows that soil is limited because it is shallow, dry, or stony.

c not used in this survey area, shows the main limitation is a climate that is too cold or too dry.

Soils within the subclasses are further divided by capability units. They are given Arabic numbers and indicate the main limitation that is responsible for the placement of the soil in the capability class and subclass. Capability units are defined as follows:

0. A problem or limitation caused by very gravelly material in the subsurface.

1. An erosion hazard, actual or potential.

2. A problem or limitation of wetness because of a high water table, seepage or flooding.

3. A problem or limitation of slow permeability of the subsoil.

4. A problem or limitation caused by coarse soil texture or excessive gravel.

5. A problem or limitation caused by fine soil texture.

6. A problem or limitation caused by salt or alkali.

7. A problem or limitation caused by stones or rock outcrops.

8. A problem or limitation caused by shallow depth of soil over bedrock.

9. A problem or limitation caused by low fertility.

An example of the this soil classification system shows that a soil that is classed as "VIe-3" is a soil with severe limitations making it unsuitable for cultivation. At least part of this unsuitability is a result of the slow permeability of the subsoil and although this soil is generally better suited to grazing, or wildlife habitat, than to other uses, overgrazed areas are susceptible to erosion.

Table 2 lists the basin area and percentage of each soil unit. It shows that the Newville Series soils make up 57.3 percent of the basin, the Nacimiento-Newville Complex makes up 15 percent, and the minor soil groups make up the remainder. These three groups are discussed below:

Newville Series

The Newville Series consists of 10 mapped soils comprising 57.3 percent of the watershed. Some of these soil units are in excess of 500 acres in size. This soil type is formed on the Tehama Formation which underlies the rounded hills between 300 and 1,100 feet elevation. In general, the surface soils are brown to yellowish brown, slightly acid and gravelly. The subsoil is a brown to reddish brown, slightly acid to neutral gravelly clay. The gravel content is higher than the underlying parent material because of weathering and selective erosion.

About 10 percent of this soil unit is Newville-Dibble Complex. These soils are typically pale brown, medium acid, and range in composition from silty loam to silty clay loam. They are moderately to well-drained with slopes from 10 to 50 percent. Runoff tends to be slow to medium where the soil has been left undisturbed. The surface is mostly well-drained but slow permeability in the subsurface layers has given these soils an "e-3" capability limitation. Erosion hazard is generally slight to moderate. Excessive grazing on steep slopes causes sheet and gully erosion.

Two soils of this series, the NrE and NrE2 occur on 30 to 50 percent slopes in the northwestern one-third of the watershed, mostly in the Pine Creek drainage. The capability class is VIe-3. These soils have rapid runoff and a severe erosion hazard rating.

Nacimiento-Newville Complex

About 15 percent of the mapped area is Nacimiento-Newville Complex. The complex may consist of 40 to 60 percent Nacimiento silty clay loam or Newville gravelly loam in any one area. These soils formed from Tehama Formation parent material and occur along ridge tops in the watershed. Slopes range from 10 to 30 percent.

The surface soil is a light brownish gray to pale brown silty clay loam. The subsoil is light gray, calcareous silty clay loam. Generally the soil is well drained, runoff is medium, permeability is slow, and the erosion hazard is moderate on these soils. Capability classes are IVe-5 and VIe-3.

TABLE 2
Soils Units: Areas and Percentages

Soils Mapping Unit		Basin Area (sq. miles)	Basin Percentage
Altamont clay, terrace	AcD	.0	.0%
Anita clay, moderately deep	Af	.1	.1%
Arbuckle gravelly fine sandy loam	Au	.0	.03%
Arbuckle gravelly loam	Av,-A,-B	1.7	2.3%
Arbuckle gravelly loam, channeled clay substratum	Az	1.6	2.1%
Arbuckle-Tehama complex	Az	1.9	2.5%
Corning gravelly loam	CwA	.0	.01%
Corning-Newville gravelly loams, eroded	CxB2	0.8	1.0%
Corning-Redding gravelly loams	CyB	0.4	.5%
Cortina gravelly fine sandy loam	Cz,-S,-X	0.6	.9%
Dibble silty clay loam	DbD,-E	0.2	.3%
Hillgate loam	HgA	0.2	.3%
Kimball gravelly loam	KoA	.0	.1%
Maywood fine sandy loam, moderately deep	Md	0.3	.4%
Maywood loam	Me	.0	.1%
Maywood loam, high terrace	Mf	.2	.3%
Nacimiento Altamont complex, eroded	NcD2,E2	.2	.3%
Nacimiento-Newville complex	NhD,E	11.3	15.0%
Newville gravelly loam, eroded	NrB,B2	.8	1.1%
Newville gravelly loam, eroded	NrD,D2	19.3	25.7%
Newville gravelly loam, eroded	NrE,E2	15.6	20.8%
Newville-Dibble complex	NvD,E	6.6	8.8%
Newville-Dibble complex, gullied	NwD,E	.6	.9%
Perkins gravelly loam	PkA	3.2	4.3%
Perkins-Kimball gravelly loams	Pm	.5	.6%
Red Bluff gravelly loam	Rg	1.1	1.4%
Red Bluff gravelly loam, hardpan substratum	Rh	.3	.4%
Redding gravelly loam	RnA	.3	.4%
Riverwash	Rr	.6	.9%
Sehorn clay and clay loam	ScD,E	.0	.03%
Tehama loam	TaA	2.5	3.3%
Zamora clay loam	Zc	1.4	1.9%
------	URBAN	2.9	3.8%
		75.2	100%

Note: Additional information on soil mapping units, slope and capability classes can be

Minor Soil Units

The remaining one-quarter of the basin is covered with a variety of soil types. The more extensive of these soil units have formed on stream terraces or stream-cut pediments. One of these is the Perkins Series, which makes up five percent of the basin. This series formed on the Lower Riverbank Formation. The soils are nearly level and well drained. The surface soil is a brown, slightly acid gravelly loam. The subsoil is a reddish-brown, slightly acid to medium acid gravelly clay loam. The permeability is moderately slow, and the available water holding capacity and fertility is moderate. Runoff is slow and there is a very low erosion hazard because of the flat slope.

The Arbuckle gravelly loams (7 percent) are nearly level to gently sloping, well drained and gravelly. They formed on the terraces along streams. The outcrops tend to be long and narrow. The available water holding capacity is moderate. There is a low erosion hazard, except where streams have undercut the bank and exposed the soil to caving.

The Corning Series (2.5 percent) formed on the Red Bluff Formation. A hummocky surface expression is characteristic. Because of the clay pan in the subsoil, low fertility, and lack of water for irrigation, little farming is done on this soil. Natural erosion hazard is moderate to low.

The Tehama Series (3.3 percent) formed on the extensive, low terraces along the major tributaries on the Upper Riverbank Formation. In Reeds Creek, the soil is mostly a loam that is well drained, has slow permeability and moderate fertility. Runoff is slow and there is a low erosion hazard.

The remaining 4 percent consists of numerous units, each comprising less than one percent of the basin. These units occur at the slope breaks between the upland ridges and flat valley floor. No one unit is very extensive because of the various changes in slope, aspect and topography. Included are such things as riverwash, rock land, and small areas of soil types that are more abundant elsewhere in the county.

HYDROLOGY

The average annual precipitation in the watershed is about 21 inches, most of which falls as rain between October and April. Extremely cold storms can bring the snow level down into the watershed, but these are rare events.

Figure 2 shows the average annual precipitation pattern for the region (Goodridge, 1966). Winter storms generated in the Gulf of Alaska usually cross this portion of California from northwest to southeast. The orographic effect of the Coast Range and Klamath Mountains causes the parallel pattern of isohyets along the northwest and west side of the valley. On occasions when a strong high pressure ridge exists along the coast, these storms are forced to the south. The resulting storm track moves up the valley in a counterclockwise motion from the southwest and causes the same general pattern of rainfall.

The maximum elevation in the 75 square mile Reeds Creek watershed is about 1100 feet. The stream flows eastward and enters Lake Red Bluff on the Sacramento River at the maximum pool elevation of 253 feet. Most of the basin topography consists of low, rounded hills and flat ridges between broad, flat-bottomed tributary stream valleys. The creek is an intermittent stream and is typically dry from June to October.

The hypsometric curve (Figure 3) shows that half of the watershed is between 300 and 600 feet elevation. The flat ridge tops are the dissected remnants of the Red Bluff pediment surface. Pleistocene terraces and Quaternary alluvium underlie the broad, flat tributary stream valleys. The terraces form flat benches that stair-step up in elevation away from the active stream channel.

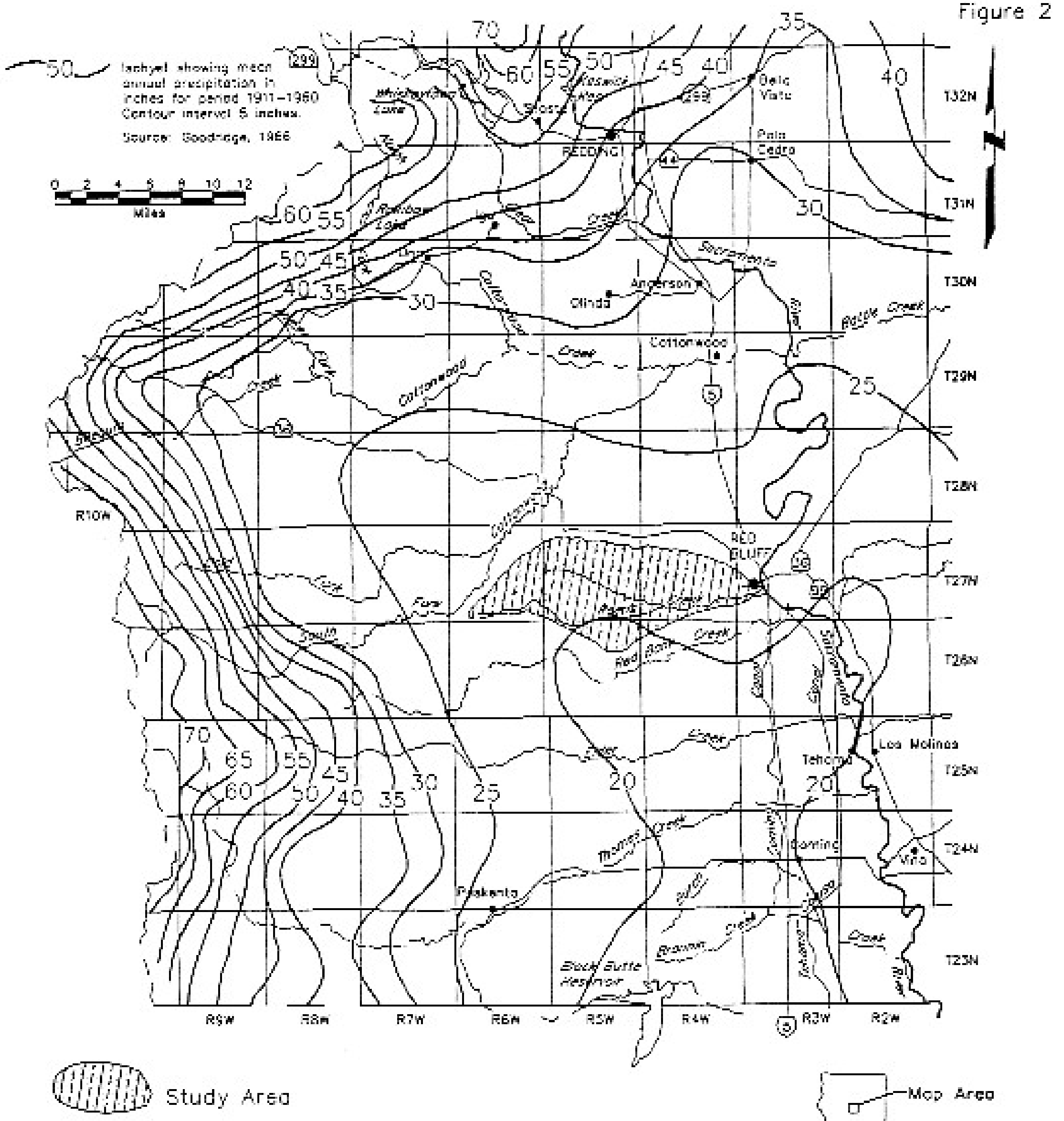
There is a distinct difference in the quantity of vegetation and depth of weathering on north- and south-facing slopes. The south-facing slopes in general have fewer trees and less brush because of the drying effects of the sun. Soil moisture is higher, vegetation thicker and rock weathering deeper on north-facing slopes.

Basin Shape

The basin shape influences the discharge characteristics of a watershed. A circular watershed with a uniform slope and permeability will result in runoff from various parts of the watershed reaching the outlet at the same time. An elongated watershed with the same area but having the outlet at one end of the major axis will cause the runoff to be spread out over time, producing lower peak flows at the outlet.

The Reeds Creek basin is approximately 22 miles long and has a maximum width of 6.7 miles. It is elongated in the east-west direction. A HEC-1 analysis of the 6-hour two inch storm for Reeds Creek shows that the Time of Concentration (TOC) for the basin is four hours (DWR, 1987).

Figure 2



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Sacramento Valley
Westside Tributary Watersheds
Erosion Study
Reeds Creek Isohyetal Map

Reeds Creek more closely resembles hydraulically a circular basin because the three major tributaries, Liza, Reeds and Pine Creeks are all of approximately equal length. They join about four to six miles above the mouth of Reeds Creek. Because of equivalent stream length, flood peaks meet at the same time, and have caused serious flooding in the lower five miles of stream.

Channel Morphology

Reeds Creek is a geologically young stream system that developed after the Red Bluff pediment formed about a half million years ago. The pediment surface sloped gently toward the Sacramento River. Elevation measurements on this surface indicates that it now slopes about 45 degrees southeast toward the Sacramento River. The maximum depth of erosion into this surface is about 250 feet. This suggests a degradation rate of about .5 feet per thousand years for the creek and about one-half to two-thirds of that for the entire watershed.

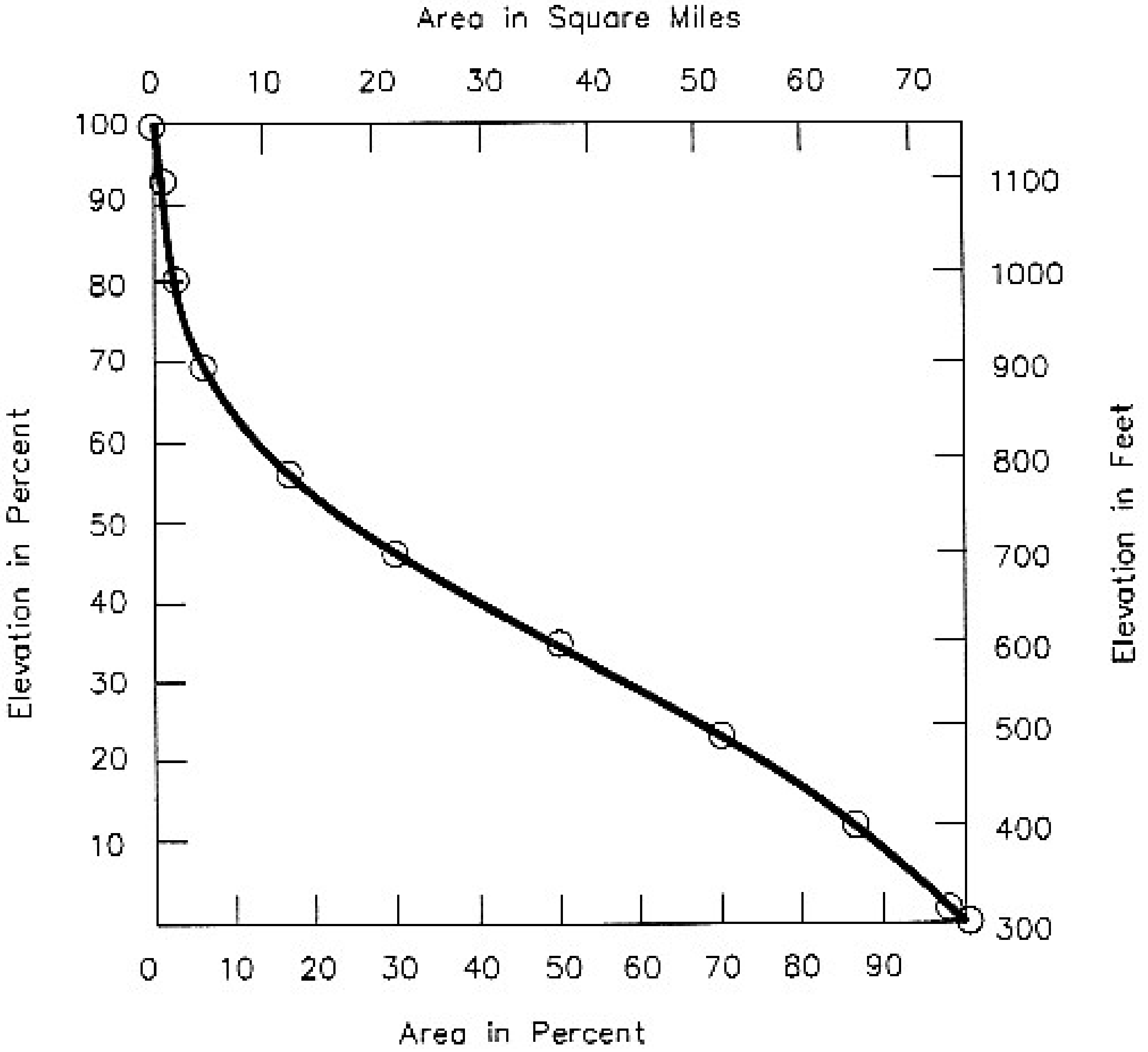
Evidence of tectonic uplift is abundant. Terrace levels progress upward in elevation with age. The sloping surface of the Red Bluff pediment has been heavily dissected. Evidence of folding and faulting have been reported in the valley (USGS, 1984).

The drainage that developed on this uniform slope has a dendritic (branching) pattern with the upper part of Reeds Creek, Pine Creek, and Liza Creek converging in the lower one-third of the basin about five miles upstream from the mouth. The fact that the stream profiles (Figure 4) have nearly the same length and gradient is probably a result of the uniform underlying geology. An interesting observation is that the central parts of each drainage are remarkably parallel. This may be due to some underlying structure not evident at the surface.

A well integrated drainage system has developed with many streams per unit area. Headward erosion has extended the drainage system upslope to the stream divides. The drainage system consists of first order streams, which are the high gradient channels in headwater areas. Second, third and fourth order streams collect and concentrate the flow. Reeds Creek is a fifth order stream in the lower half of its length.

Most of Reeds Creek's tributaries are in narrow, incised channels that cut through flat bottomed valleys for most of their lengths (Photo 6). This configuration is effective in moving bedload through the system. The percentage of bedload in storage in Reeds Creek is probably significantly lower than other westside streams because of the efficiency of the channel during high flows.

The terraces that contain most of the gravel in the Reeds Creek basin are isolated from the active channel by steep banks. In some reaches, such as North Fork Reeds in Burr Valley, Liza Creek, and along parts of Pine Creek, the stream flows in multiple channels. In other reaches, notably downstream from Wilder Road to the mouth, the channel is alluvial.



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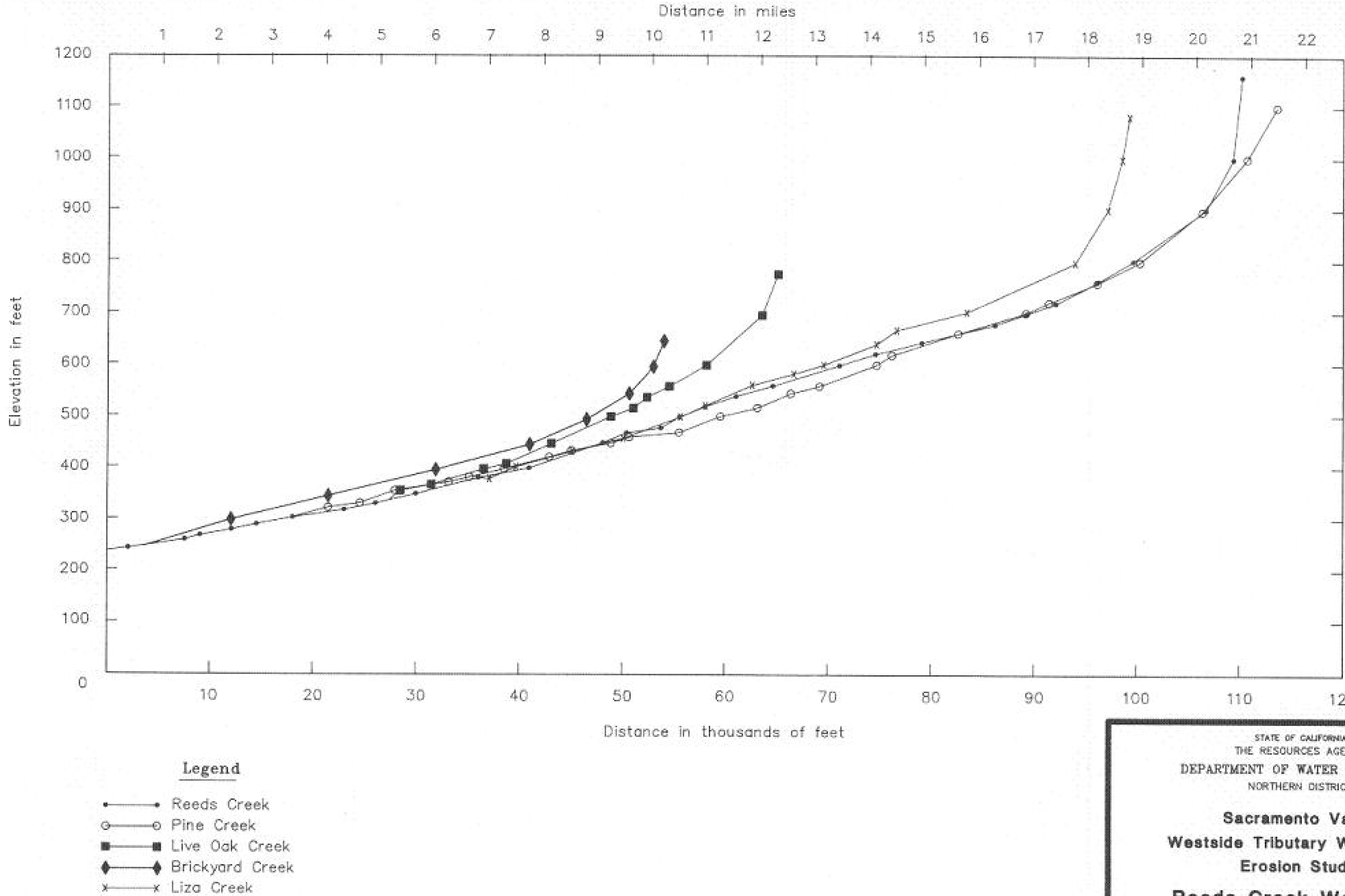
Erosion Study
Reeds Creek Hypsometric Curve



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Erosion Study

Reeds Creek Watershed
Stream Profiles

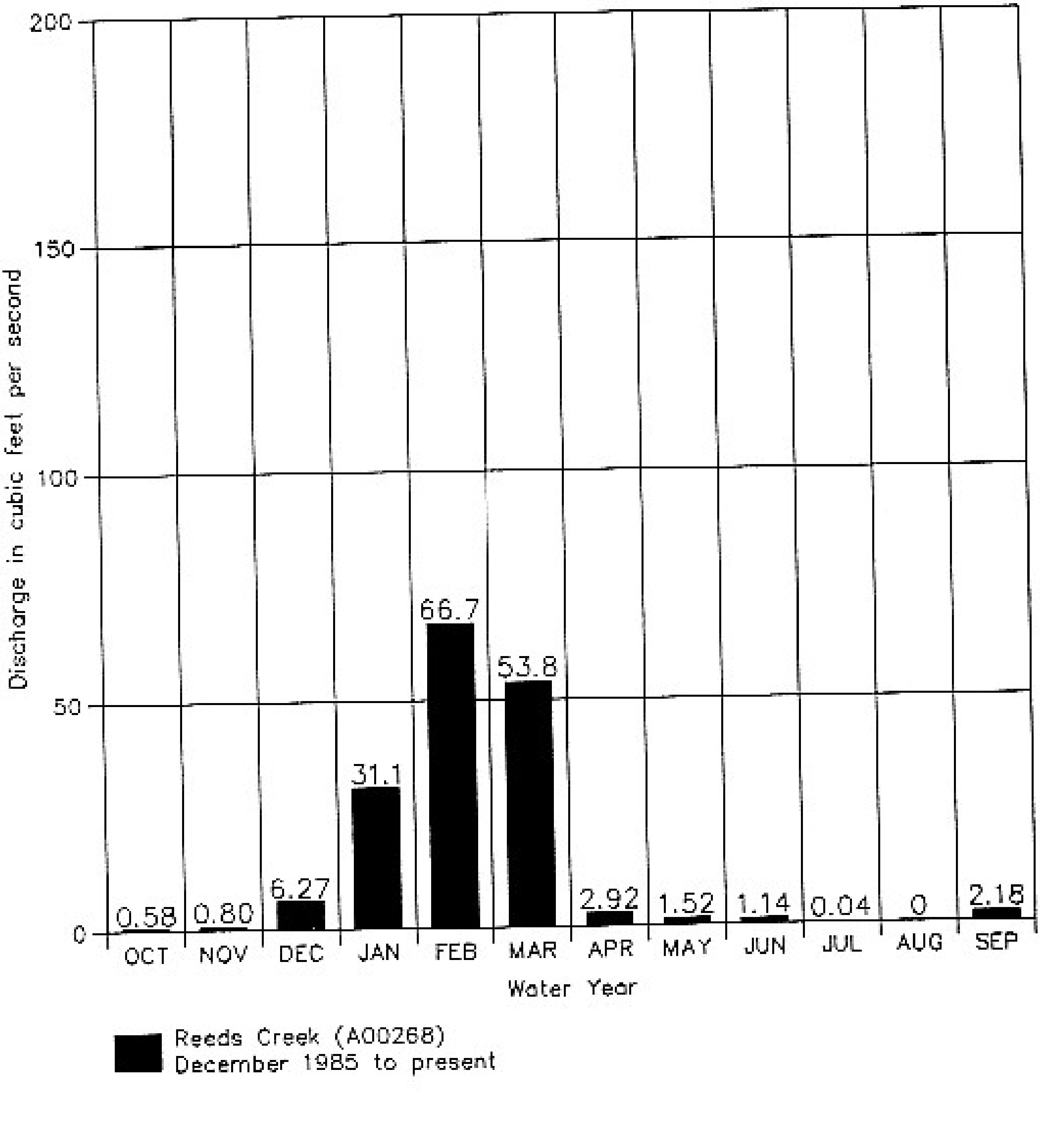
October 1991

Human induced changes have also affected the watershed. The operation of the Red Bluff Diversion Dam have caused large short-term changes in the deposition-erosion cycle. Land use changes such as reduction in trees and groundcover, and soil compaction by animals, have caused increased runoff and peak flows.

Photo 6. Most of Reeds Creek, such as here near the Hesse Road bridge, and the tributaries, are narrow and incised into the Quaternary Terrace deposits and the Tehama Formation.

Stream Discharge

Reeds Creek drains an area of about 75 square miles. Peak flows occur between October and April in response to rainfall. During the summer months, the stream is normally dry except for isolated low places that tap the free water table and have standing water.



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Erosion Study

Average Mean Monthly Discharge
Reeds Creek

There is one active stream gage in the Reeds Creek basin. It was installed in November, 1984 downstream from Wilder Road and is maintained by DWR as part of a flood warning system. A statistical correlation between Reeds and Red Bank Creek gages was performed to extend the short-term flow record. The Red Bank gage has 19 years of records. Linear regression was used to correlate the two stations between 1986 and 1989. Red Bank records from 1984 and 1985 were not used because of incomplete data.

Figure 5 is a bar graph showing the mean monthly flow data and the adjusted values based on the Red Bank gage correlation. It shows that Reeds Creek is an intermittent stream that generally begins flowing in the late fall and continues until early summer. The average Mean Monthly Discharge measured at the Wilder Road gage on Reeds Creek is highest in February and there is normally no surface flow in the creek from July to October. The five years of data are shown by the solid bars. The extended record is shown by the dashed bars. The mean calculated from these recorded data is probably not very accurate because of the extremely short period of record. However, the measured mean flow during this four-year drought period is low when compared to the adjusted period of record.

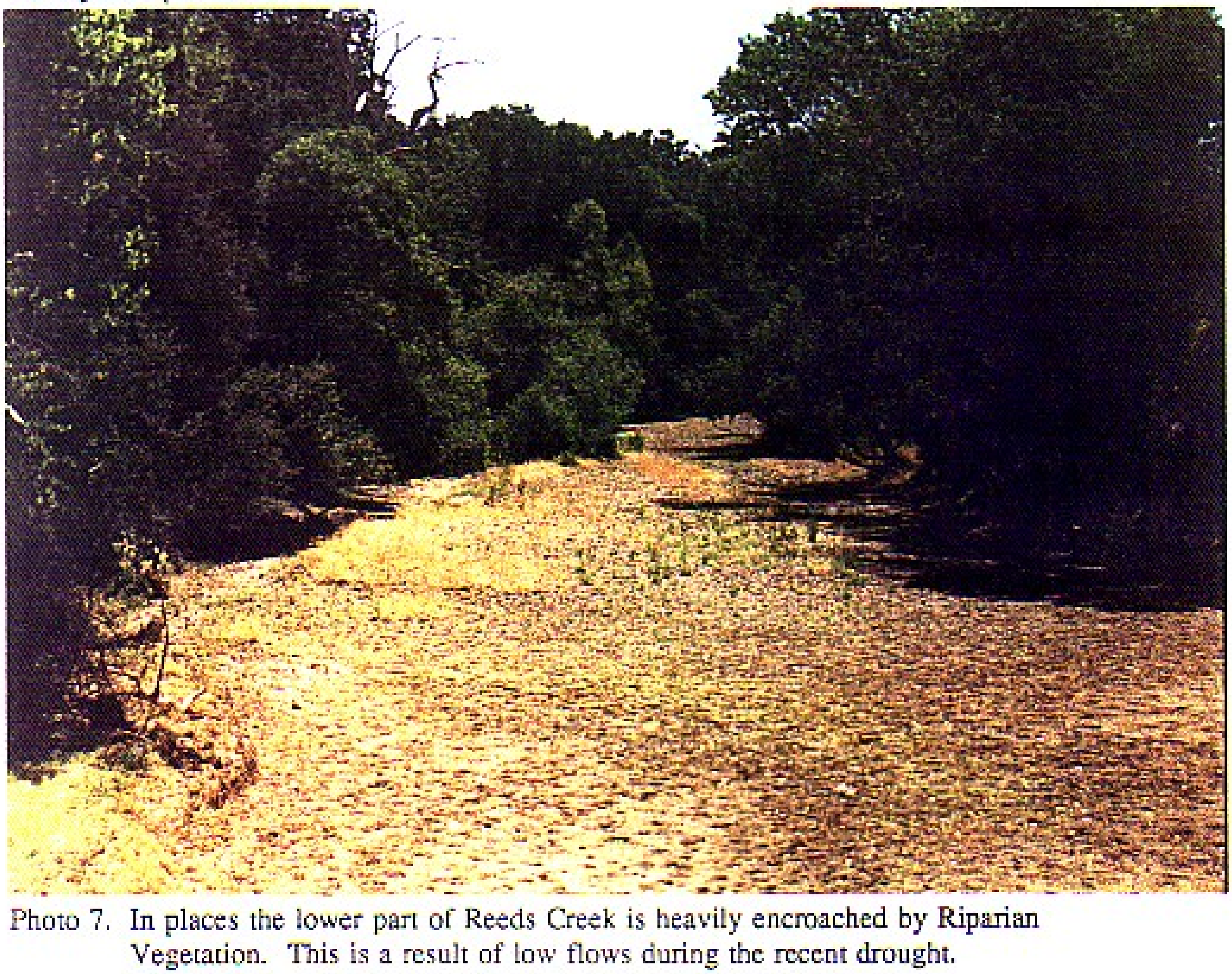


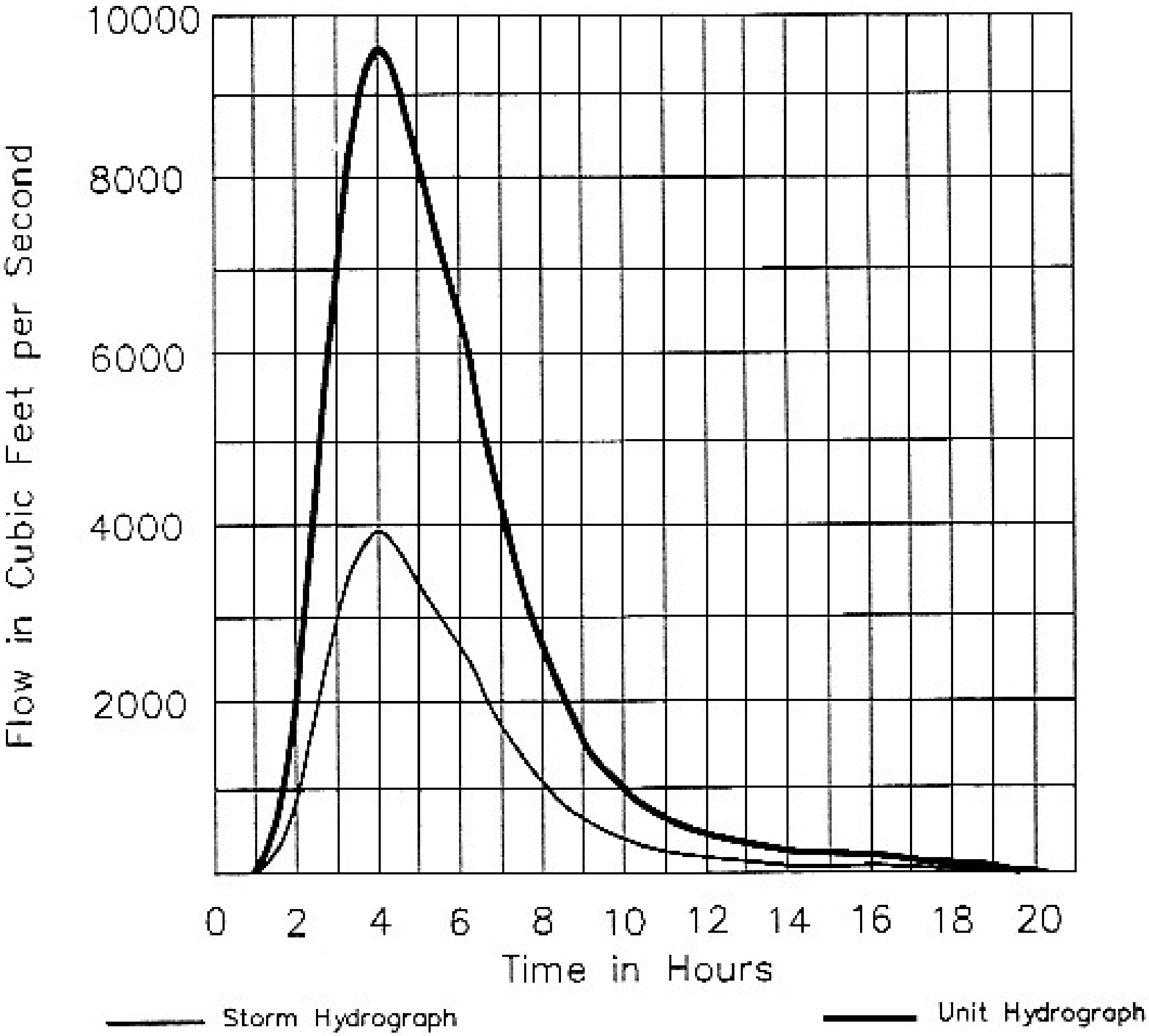
Photo 7. In places the lower part of Reeds Creek is heavily encroached by Riparian Vegetation. This is a result of low flows during the recent drought.

A flow duration curve was not constructed for this stream because the period of record is too short. Instead, a "unit hydrograph" was made to predict the runoff from a 2-inch rainfall event of six-hour duration. Figure 6 shows the predicted hydrograph and compares it to the February 1986 storm event. Runoff from this watershed peaks rapidly in response to rainfall. A high percentage of the precipitation that falls on the basin will run off immediately as surface flow during most rainstorms. The low base flow preceding and following storms suggest that this watershed has low bank storage and percolation. This basin also has a very efficient flood routing due to the basin shape and incised channel configuration discussed previously.

The Department of Water Resources (1987) published a peak flood flow diagram for the Red Bank gage and an estimated curve for Reeds Creek. The Reeds Creek curve is shown in Figure 7. The diagram shows the expected curve for Reeds Creek based on calculated peak flow events on Red Bank Creek. The slope of the flow exceedence curve for Reeds Creek is assumed to be similar because of the similar geology, vegetation cover and rainfall between the two basins.

Photo 8. The upper part of Brickyard Creek, shown here, and Liza Creek, meander between the Quaternary Terrace deposits.

Figure 6



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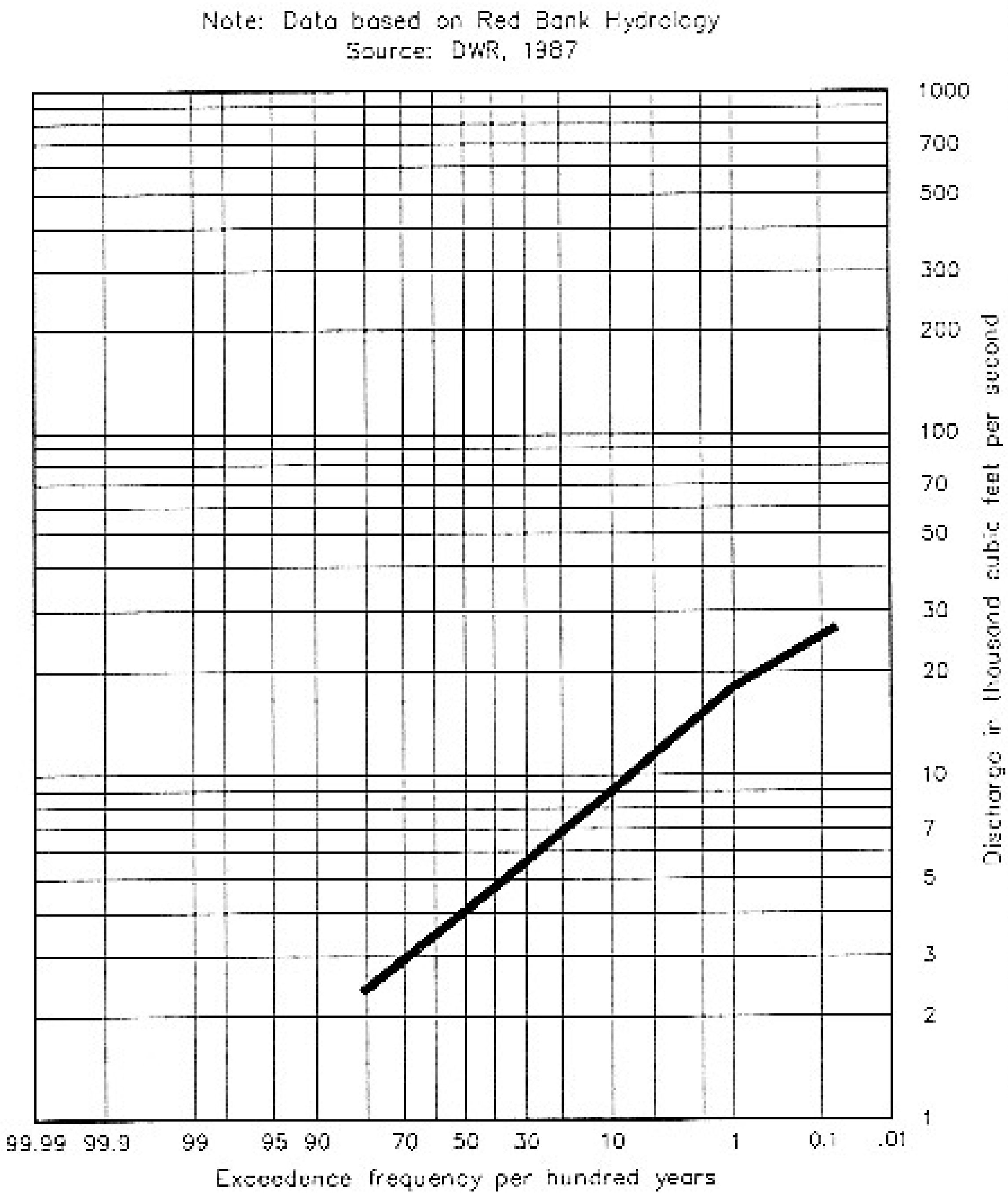
Erosion Study
Reeds Creek Unit Hydrograph



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Erosion Study

Peak Flood Flow Frequency
Reeds Creek Near Mouth

VEGETATIVE COVER

Before European man settled the Sacramento Valley, it is estimated that about 90 percent of the basin was blue oak woodland, about five percent live oak riparian woodland and five percent grassland. After the mid-1940s and the end of World War II, a large part was denuded and converted to grassland, urban use or dryland agriculture. Table 3 shows the present amounts of urban, cultivated land, grassland and oak woodland.

TABLE 3
AREAS AND PERCENTAGES OF VEGETATION TYPES

VEGETATION TYPE	ACRES	PERCENT
Urban	1670	3
Cultivated	1000	2
Grassland and Savannah	36,030	75
Oak Woodland	9,500	20
TOTAL	48,200	100%

Blue Oak Woodland

The major vegetative type is the Quercus douglasii or blue oak woodland. Some individual live oak (Quercus wislizenii) and valley oak (Quercus lobata) may be interspersed in valley areas. Poison oak (Rhus diversiloba) is the predominant shrub. Under natural conditions, the blue oak woodland grades gradually into grassland where the soils, slope, and slope aspect limit tree growth.

The original blue oak woodland probably varied in crown or canopy cover from about 5 percent to nearly 100 percent. Though tree density varied, heavily wooded areas graded smoothly into less dense stands, and pockets of dense growth characteristically followed drainage courses and land contours. The present distribution and density of blue oak woodland reflect the effects of land conversion. Major areas that have been converted to grassland (Photo 9) are readily discernible by differences in canopy density and distribution, abrupt straight-line boundaries along section and property lines, and other obvious anomalies.

The present blue oak woodland stands may be subdivided into three categories based on canopy density:

Blue Oak Woodland (40 percent and greater tree cover). These areas are characterized by natural or nearly natural stands of blue oak. The trees are evenly distributed and undisturbed by harvesting activity. This unit occurs in about five percent of the basin.

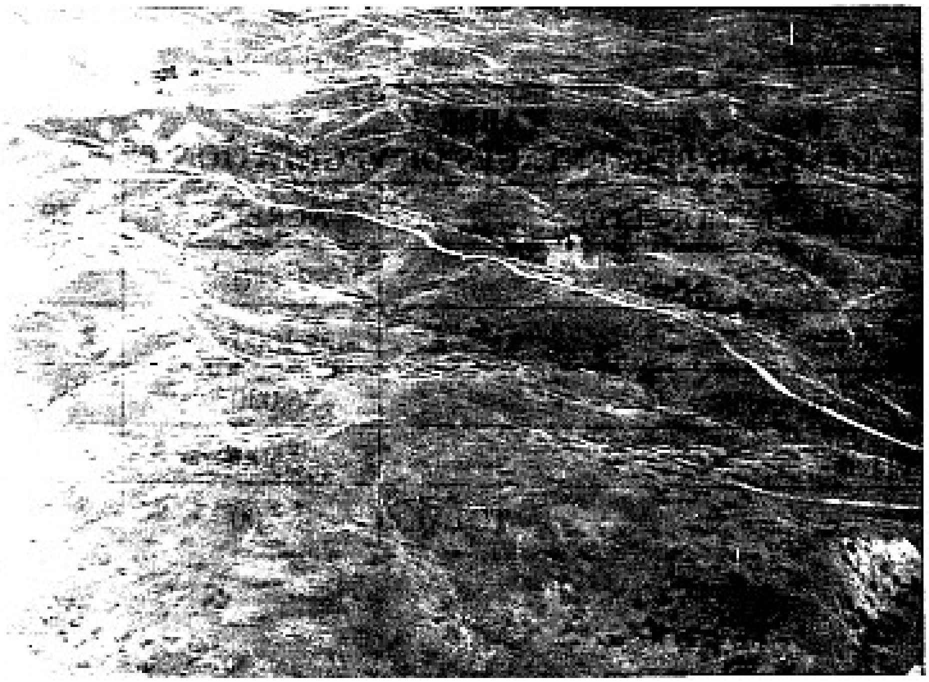


Photo 9. Large areas of the watershed has been cleared of oaks, such as this recent conversion shown in this 1986 photograph.

Blue Oak Woodland (15-to-40 percent tree cover). These areas are predominantly mixed woodland and grassland. Tree stands are irregular and patchy; hill crowns are commonly bare of trees, and trees are most abundant on steep slopes and in gullies and ravines. Many places show evidence of selective cutting. This unit constitutes 15 percent of the watershed.

Blue Oak Woodland (0-to-15 percent tree cover). These areas are predominantly woodland converted to grassland with very sparse stands of blue oak remaining. Some natural savannahs are included.

Blue Oak Woodland Regeneration

Tehama County was first settled by Americans in 1844 with grants obtained from the Mexican government. The area was heavily forested at the time, with evergreen conifers in the mountains of the east and west, and oak woodlands in the rolling foothills, and a mixture of valley oak, sycamore, cottonwood, black walnut and other riparian vegetation along streams. Most of the valley woodland has been converted to row crops, orchards or urban development. The blue oak woodland of the foothills has been used primarily for grazing of livestock.

The Mediterranean climate, characterized by hot dry summers and mild wet winters typifies the valley. The precipitation in the Reeds Creek basin varies from 19 to 23 inches. Blue oak can occupy sites which receive as little as 10 inches of precipitation annually (DeLasaux and Pillsbury, 1987).

The blue oak community forms a nearly continuous ring around the central valley of California, generally between 300 and 3,600 foot elevation. It is essentially a two-layered community. An overstory canopy, 15-45 feet tall, is 30-80 percent closed, and blue oak, with an importance value above 67 percent is dominant. Sapling and tree density combined is usually less than 80 per acre, but dense stands can reach 400 per acre. Tree life span is <300 year and tree girth is modest, averaging 8-12 inches diameter at breast height.

Oak woodland generally occurs on moderately rich, loamy, well-drained soils with neutral or slightly basic pH. Topography is often gently rolling to steep (10-30 percent). Oak woodland often occurs in a mosaic with grassland, savanna (<25 percent tree cover) and chaparral - a mosaic that reflects differences in slope, aspect, soil depth and frequency of fire more than differences in climate (Barbour, 1986).

Except for some open prairie in Southern Tehama County west of I-5, most of the foothill area on both sides of the valley is covered with woodlands comprised mainly of blue oak, along with valley oak, interior live oak, canyon live oak and digger pine. An estimated 600,000 acres of Tehama County is in this hardwood-range type, 270,000 acres of which are in areas made largely inaccessible by rocky or steep terrain.

There is concern for the oaks in California for several reasons: 1) The hardwood-rangelands support species such as blue oak, valley oak, and Engelman oak which appear to regenerate poorly; 2) These lands experience a wider range of conversion pressures, and cover a much larger area than the hardwood-supporting conifer regions; 3) The Forest Practices Act does not currently affect the hardwood-rangelands; 4) The California Department of Forestry has more information on conifer regions than hardwood regions (Doak and Stewart, 1986).

White (1966) made a detailed study of 94 acres of blue oak woodland in the Central Coast Range, Monterey County. Two blue oak age groups were evident: 60-100 yr old and 150-260 yr old. Successful establishment had been declining for the past 90 years and essentially no establishment had taken place in the last 30 years. Establishment appeared to be episodic, with the most recent flush occurring in the late 1870s. The flush of establishment in the 1870s could have coincided with low herbivore population numbers and optimal fall germination conditions, followed by mild summers.

It is known that all oak tree species are capable of sprouting in California, though valley oak and blue oak lose the ability once they reach a certain mass or age.

In a statewide survey of oak stands, they found the average density to be 61 stems per acre. Tree cover averages 36 percent statewide (Muick and Bartolome, 1987).

Acorns may make up 90 percent of the diet of some California deer herds in the fall and winter. In the valley, a majority of the acorns come from blue oaks.

The main commodity markets for hardwoods are firewood, pulpwood, lumber, and biomass for energy production. The major land-based activities which affect hardwood removal and retention are range improvement, timber stand improvement, parcelization and residential expansion, and agricultural conversion.

Range improvement through hardwood removal is an intensification of an existing use. The relative permanence of the resulting cover change is difficult to predict and is largely a function of removal techniques, future management, and biological factors. Hardwood removal has historically been prohibitively expensive, prompting government assistance. The growth in demand for firewood has aided in the accomplishment of desired range improve- ment objectives. Firewood values have become increasingly relevant to hardwood-rangeland managers and are now a major driving force behind many range improvement practices. Only the landowner knows when range improvement is the primary objective, a secondary objective, or merely an excuse for hardwood removal. Positive stumpage values over and above the costs of removal and clean-up provide an incentive to remove hardwoods which is unrelated to range improvement objectives (Doak and Stewart, 1986).

Estimates of overall residential firewood consumption for 1981 ranged from 1.5 to 1.9 million cords. Based on information collected by Lee (1984) and Doak and Stewart (1986), the total amount of indigenous hardwoods cut for firewood in California does not appear to exceed 160,000 cords per year and may be less. Native hardwoods would therefore make up less than 10 percent of total firewood consumption in California.

While some landowners leave as much existing vegetation in place as possible, others have converted the existing cover to plants more common to urban settings. Horse or other stock raising on these parcels often results in severe damage to existing vegetation through over-grazing and soil compaction. High density developments will significantly alter its character in terms of wildlife habitat. The Tehama General Plan estimates that 10,169 acres of land will be needed for residential growth in the period 1980-2000. Future expansion will mostly occur in the oak woodlands, especially in the lower foothills to the north and west of Red Bluff (Doak and Stewart, 1986).

Large scale oak removal began in the 1940s when ranchers began pulling out oak trees with large crawler tractors. The primary objective was to increase forage through the complete removal of trees and brush. Blue oak was the primary species involved. Federal funding for these capital intensive projects was available through the County Agricultural Soil Conservation and Stabilization Committee (ASCS) from the mid-1940s through the late 1960s. Techniques for successful removal were refined over the years. Oaks were pushed over with bulldozer blades and even with large anchor chains drawn by tractors. Herbicides were used to kill trees in place. Burning, whether in piles or broadcast, was used to reduce the amount of slash on the ground. Approximately 105,000 acres, primarily on the west side, were treated in this manner. Resprouting of stumps was often a problem when roots were not removed. It has been estimated that one third of the above acreage has since grown back through sprouting to densities equal or greater than pre-treatment. Roughly another third has partially resprouted but remains more open than originally. The only ASCS funded range improvement work since about 1970 has been in these areas of regrowth where advisors of the original project failed to give sufficient instructions concerning sprout prevention.

The firewood market has recently provided an opportunity to accomplish range improvement projects at a profit. Several large firewood cutting operations have been taking place in Tehama County since the late 1970s. Clearcuts of several square miles in size can be found in parts of northwestern Tehama. Often the primary objective behind these stumpage sales is short term cash gain with range improvement remaining only a secondary objective. Yields may vary from three to twelve cords per acre, but eight cords is typical.

Concern over hardwood harvesting has also focused attention on the possible expansion of the scope of the Forest practice program. The Forest Practice Act defines timberlands primarily in terms of commercial timber harvest. Until recently, hardwoods had little or no commercial value. Consequently, they were not explicitly addressed by the state's act and rules. At this time, the Board of Forestry has chosen to adopt a cooperative, non-regulatory policy which was outlined in the report "Policy Options for California Hardwoods" (1986) described in CDF (1988).

About 272,000 acres of oak woodland-grassland in California were converted to urban and agricultural land between 1950 to 1980. This represents about 20 percent of the 1,361,000 acres present in 1950 (CDF, 1988).

Bolsinger (in Bartolome, et al., 1986) determined that the area occupied by hardwoods on rangeland (savannas and woodlands) decreased by over one million acres since 1945. Most of this decrease was due to clearing for rangeland improvement. More recently, in the approximately 10 years prior to 1981, over 100,000 acres of blue oak and lesser amounts of other types were converted to non-forest.

Of the 17 species of oaks that occur in California, blue oak is among those of greatest concern because of its extent, use, and apparent lack of regeneration. Moreover, blue oak is the primary species that ranchers clear from their lands to increase grazing capacity and generate income. It is the dominant tree in the oak woodlands surrounding the inland valleys and Coast Ranges.

Oak removal effects on livestock forage production depend on local edaphic and climatic conditions as well as oak density. At the U.C. Sierra experiment station foothills site, tree removal increased forage production, while at a southern Sierra Foothill site, forage production under oaks was higher than in adjacent grassland. The open status of the savannah at the southern site on the San Joaquin Experimental Range coupled with light textured granitic soils likely make the site a relatively xeric one. Oak canopy cover probably benefits forage production by reducing transpiration of understory forage plants thereby extending the growing season. In a very different woodland situation on a slightly north-facing slope at the northern site on the foothill range field station, heavier-textured soil, higher rainfall, and additional sunlight due to oak removal clearly enhanced forage production (Menke, 1987). Reeds Creek probably has conditions more similar to the southern site.

Forage production enhancement due to oak removal, above that of open grassland, lasts for only approximately 15 years. Managers must realize that oak woodland conversion to open grassland creates rangeland with productivity of open grassland, but that the enhancement of production is not sustainable for more than about 15 years. The length of the enhancement period obviously must depend on the age of the oak stand and the accrued standing crop of nutrient in the understory soils. Under poorer, open deciduous oak savannah conditions, the practice of this type of conversion is not justified because forage and wildlife habitat losses probably outweigh forage enhancement values (Menke, 1987).

Areas with low soil fertility have also been shown to have higher forage production beneath the trees, apparently benefitting from the fertility contributed by fallen leaves (Kay, 1987).

Brush and tree eradication on foothill range also removes the roots of woody vegetation. These constitute a major subsurface stabilizing element of a slope. Conversion also amplifies the impacts of precipitation on the soil surface. The opportunity to avoid future soil loss and gully formation problems should provide adequate incentive for retaining groups of trees on steep hillsides, on rock outcrops or in natural drainage ways (Raguse, et al., 1987).

Live Oak Riparian Woodland

The live oak riparian woodland is rare. Major plants include live oak (Quercus wislizenii), sycamore (Plantanus racemosa), California buckeye (Aesculas californica), cottonwood (Populus fremontii), and willow (Salix spp.). The predominant shrubs are poison oak and wild blackberry. This forest type is most commonly found near the major drainage channels (Photo 10) since most of these species have a high water requirement. Live oak riparian woodland constitutes a small percent of the watershed.

Photo 10. Live oak and riparian woodland occurs in narrow corridors along the larger streams.

Open Grassland

Open grassland generally has less than five percent or fewer trees but may range to as high as

15 percent. About 75 percent of the basin is open grassland consisting of annual and perennial grasses and forbs. Most of the grasslands were probably originally blue oak woodland and have been nearly 100 percent converted to grassland by oak harvesting or conversions. Wildfires may have created patches of open grassland and mixed-age stands of blue oak, live oak and brush. Grassland conversions constitute about 65 percent of the watershed. The current major land use in these areas is seasonal grazing with some dryland farming.

Cultivated

The areas designated as cultivated were identified on 1958 through 1988 aerial photography. Larger areas have been cultivated only periodically during the last 30 years are not included. Alfalfa, winter wheat, oat, hay, and other forage types are the major crops grown. Less than two percent of the watershed is currently cultivated.

Urban/Suburban

The major areas of urban and suburban development are clustered at the eastern end of the watershed near the city of Red Bluff and along tributary streams west of the city limits. Housing densities range from high density urban with paved streets to 5-20 acre suburban tracts with individual homes and gravel roads. About three percent of the total basin has been urbanized.

HISTORIC LAND USE

Significant vegetation changes have occurred in the 30-year period since the 1958 soil survey photo base was flown. Table 4 below is a tabulation of the acreages in each vegetation type in 1850, 1958, 1979 and 1990. Plate 3 shows the aerial distribution of the vegetation changes.

TABLE 4
CHANGES IN HISTORIC LAND USE AREAS, IN ACRES

Vegetation Type	1850	1958	1979	1990
Urban	0	600	1,670	1,670
Grassland*	4,820	22,100	27,130	37,030
Oak Woodland	43,380	25,500	19,400	9,500
			Totals	48,200

* includes cultivated areas

Most of the basin was once covered with dense stands of blue oak. Aerial photos (DWR black and white, scale = 1:24,000) show that by 1958, 47 percent had been cleared and converted to grassland, tilled or urban areas. This includes most of the area between Liza and Reeds Creeks, the lower portion of the Brickyard Creek, and a major portion of the area between Reeds Creek and Ridge Road.

Since 1958, about 16,000 acres of additional woodland has been either thinned or clear cut and converted to open grassland. This was done primarily to improve or increase grazing land. However, in some of these areas, slopes are too steep and soils are too poor to justify clearing for grazing enhancement. Since about 1980, most of the oak harvesting is for firewood.

Today approximately 80 percent of the Reeds Creek drainage is grassland, tilled or urban. We also estimate that only 4 to 13 percent of the original virgin blue oak woodland remains. This means that about 90 percent of the basin has been partially or completely harvested. The wooded areas shown on Plate 3 represent remnants of the original woodland. Where woodland has been converted to grassland, the major land use is seasonal grazing with some dryland farming. The Tehama County Soil Conservation Service suggests that without the recycling of nutrients from leaf litter, these areas are gradually losing productivity and the ability to produce new soils (personal communication, Mark Parson). According to a survey of range managers, oak trees help to improve watershed conditions by contributing to higher infiltration rates, soil fertility, and increased organic matter (Jones & Stokes, 1991).

Most of the historic land use change occurred in the western two-thirds of the watershed on large tracts of privately owned land (Photo 11). The eastern portion of the basin has had a minor increase in urban acreage and a decrease in cultivated acreage.

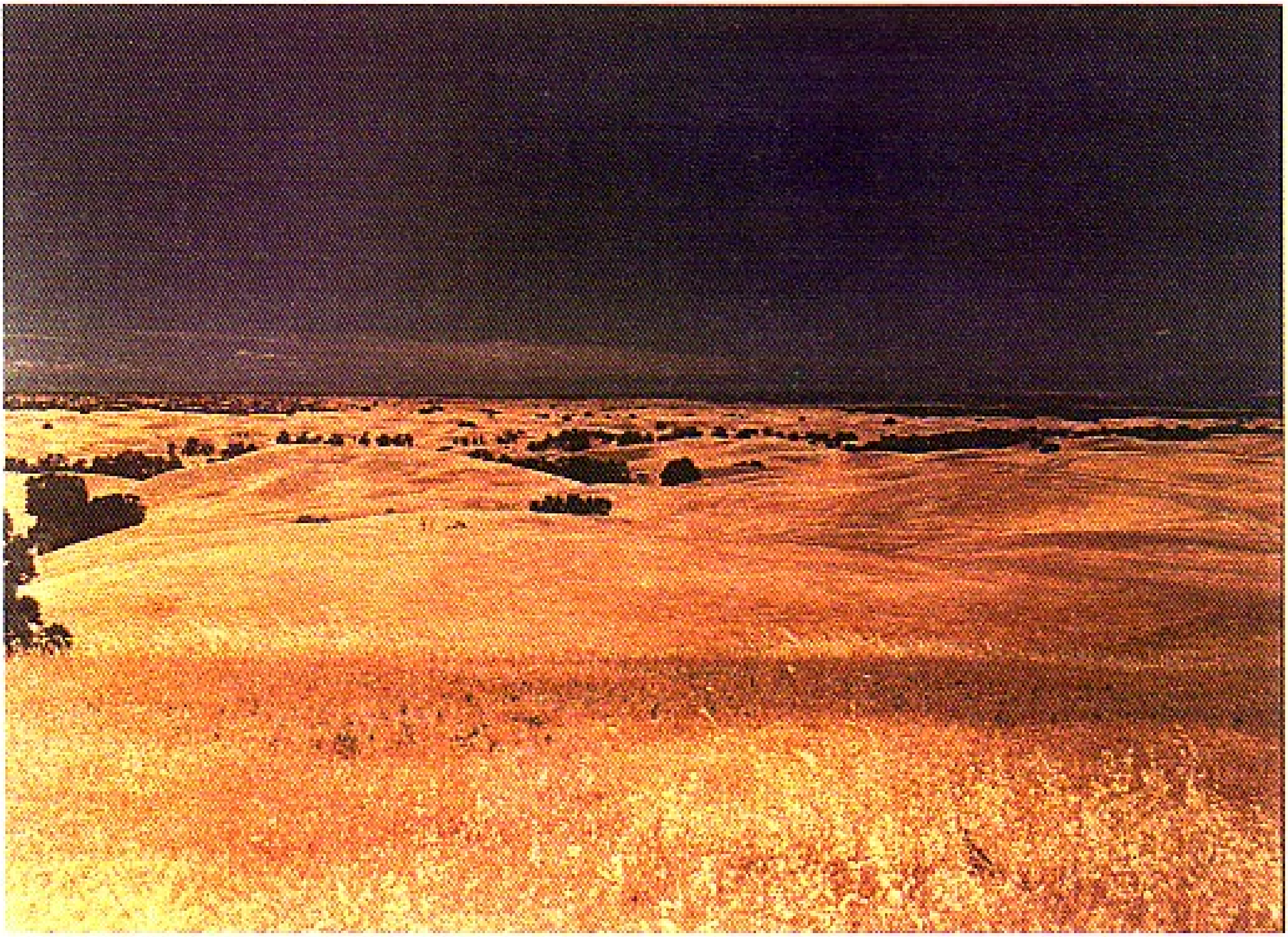


Photo 11. Open grassland constitutes about 77 percent of the watershed.

The entire Reeds Creek watershed is privately owned and managed. At the turn of the century, the area was used extensively to graze large herds of sheep and cattle. Large acreages in the valley bottoms and low foothills were also cultivated for winter wheat. The land use has changed through time in response to economic pressures. Today, it can be roughly divided into two land uses based on the subdivision lot densities. The western two-thirds of the basin is in large land ownership parcels of 80 acres or more. These areas are managed as ranches. In most cases, the areas consist of rolling oak and grasslands and are used for seasonal livestock grazing, mostly cattle.

The hatched area on the east side of the watershed is subdivided into parcels of less than 80 acres with individually owned lots in rural or urban settings. Beyond the Red Bluff City limits, these areas are being converted into suburban residential lots. At present they are interspersed with larger oak woodland and grassland acreages. There is some cultivation on the terraces in the flat stream valleys. The overall land use is highly variable depending upon the land owner. Some small acreage owners graze cattle, horses, and less often goats and hogs. Other parcels have been left largely natural with only an access road and one residential home on 2- to 40-acre lots.

The City of Red Bluff urban area lies at the eastern end of the watershed where high lot densities and paved streets predominate. The riparian corridors of Brickyard and Reeds Creek cut through the developed area. There is a partial levee system along the lower reach of Reeds Creek to help protect the urban area from overbank flooding during high runoff.

PART III: WATERSHED EROSION OBSERVATIONS

STREAM CHANNEL CHANGES
TURBIDITY
EROSION AND INSTABILITY
SEDIMENTATION

STREAM CHANNEL CHANGES

In June 1986, DWR surveyed seven bridge cross-sections and compared them to Tehama County Road Department bridge "as-builts" to document historic channel changes. Figure 8 shows the locations of the sections in the watershed. Five of the sections are on the main stream, one is on a major tributary (Pine Creek), and the other is on a minor tributary (Brush Creek). All the stream bed cross-sections are in the Tehama Formation.

The bridge sections suggest that only minor channel degradation has occurred at most of the sections. The large changes in the lower part of Reeds Creek are caused by the operation of the Red Bluff Diversion Dam. The sections are discussed in more detail below.

The Johnson Road Bridge on Reeds Creek is in Section 32, T27N, R5W about 10 miles west of Red Bluff. When this bridge was built in 1919, the average channel elevation was 34.7 feet, local datum. In 1986, the average channel elevation was 32.7. This two feet decline over 67 years suggests that the average annual degradation rate is 0.03 ft/yr at this site.

The Hesse Road bridge is in Section 4, T26N, R5W. The present channel is cut into Tehama Formation and has steep, non-vegetated sides and a relatively flat bottom overlain with a thin deposit of alluvial gravel. Between 1971 and 1986 the average channel elevation degraded 1.1 feet (0.07 ft/yr). Based on the present conditions, it appears that the channel has been eroding evenly at this site.

The Wilder Road bridge is on Reeds Creek about 2.5 miles above the streams confluence with the Sacramento River. This bridge site is in a fairly straight section of creek. It is bordered by low fluvial terraces and has a bed of thin, alluvial sand and gravel. The channel is slightly wider upstream and downstream from the bridge site. The bridge abutments do not appear to present a major constriction to the stream flow. When this bridge was built in 1948, the average channel elevation was 342 feet. By 1986, it had degraded 3 feet to 339 feet elevation. This 3 feet decline over 38 years suggests an average annual degradation rate of 0.08 ft/yr at this bridge site.

The South Jackson Street Bridge crosses Reeds Creek in the urban area of Red Bluff. Much of the terrace area that borders the stream channel has been subdivided and developed. The narrow, straight channel section that remains has an alluvial bed and vegetated sand and gravel channel sides. Since 1965, the average stream channel elevation has increased from 254.5 feet to 257 feet, an average aggradation of +0.12 ft/yr over the period of record.

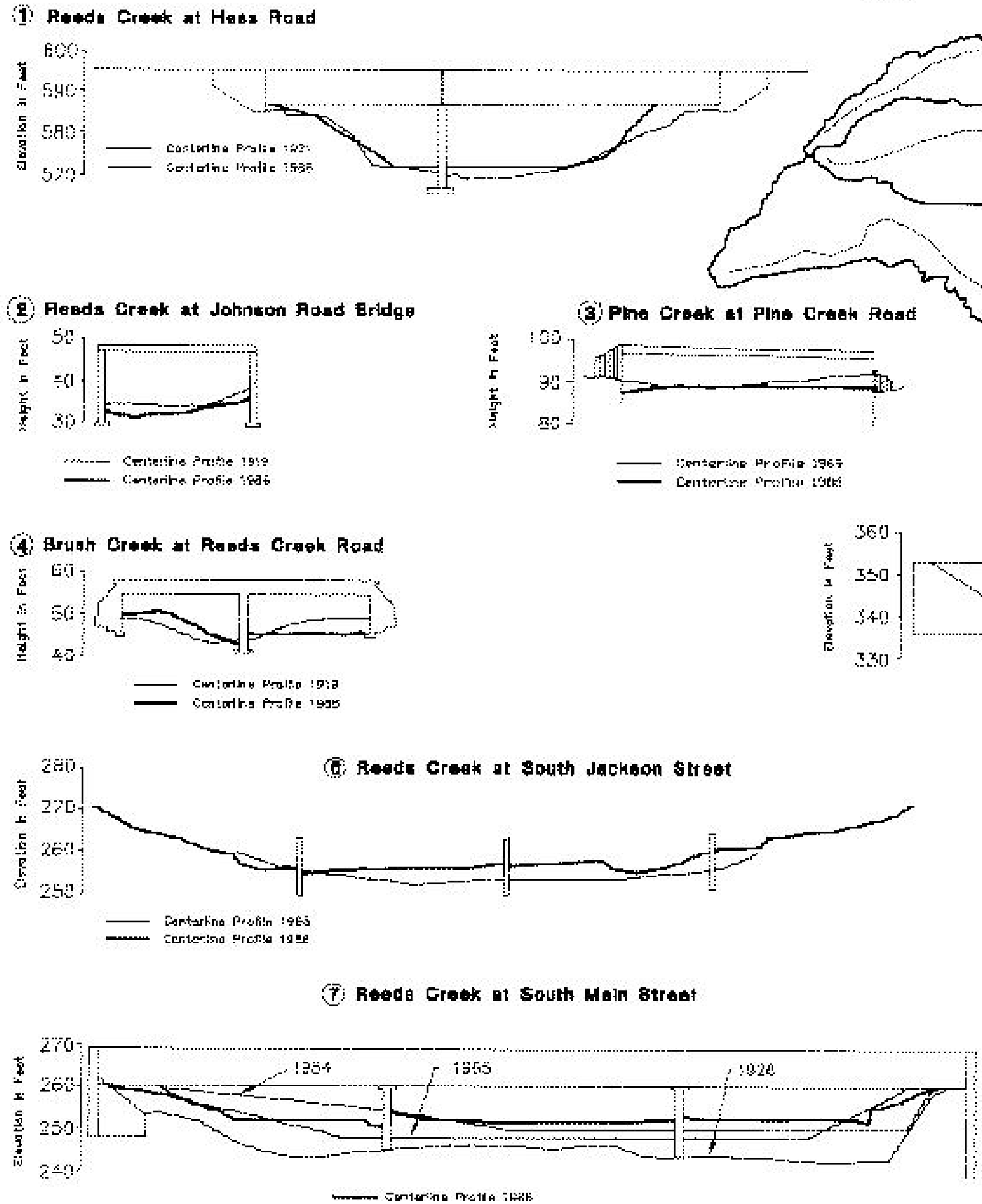
The aggradation at south Jackson Street and below this point was investigated in 1986 as part of a flood study (DWR, 1987). Figure 9 shows a profile of the lower 3200 feet of channel. About 4 feet of aggradation is evident between the construction of the Red Bluff Diversion Dam in 1967 and 1986, for a total of about 56,000 cubic yards of sediment. Major stormflows in March 1983 and February 1986 contributed the majority of this sediment. The U. S. Bureau of Reclamation dredged the mouth of Reeds Creek several times to remove accumulated sediment.

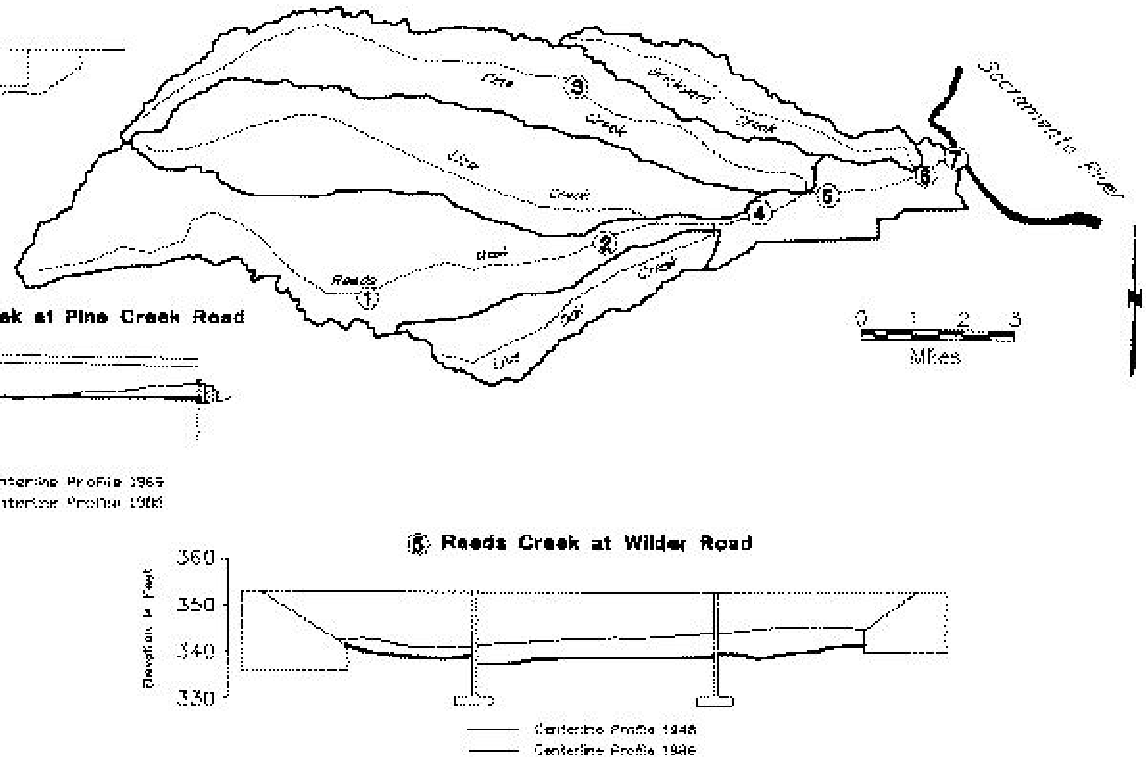
Since 1986, the dam has been opened during the winter months and the accumulated sediments are beginning to scour out of the reach. The major finding of the study is that the aggradation was caused in part by the backwater effect of the Red Bluff Diversion Dam.

The Reeds Creek channel section at Main Street is within the normal pool elevation influence of the Red Bluff Diversion Dam (253 feet). The diversion dam was first closed in 1966. The gates were used to maintain the normal pool elevation except when flows exceeded 55,000 cubic feet per second. Beginning in 1986 the gates were continuously open during the winter months. Sedimentation in the lower reach of Reeds Creek is highly influenced by the dynamic hydrologic conditions in this backwater area.

The record of channel elevation changes since the bridge was constructed in 1926 shows a net increase of nine feet. Although this suggest an average annual aggradation rate of +0.12 ft/yr, the infilling has been episodic. Aggradation occurred between the 1926-1954 survey; degradation occurred between 1954 and 1965 surveys; aggradation occurred between 1965 and 1986.

In March 1990, DWR re-surveyed fourteen cross-sections established during the 1987 Reeds Creek Flood Study. The locations are shown on Figure 9 and the cross-sections in Figures 10 to 16. They show that, since the dam began opening its gates during the winter runoff, approximately 35,000 cubic yards of gravel have been flushed out of this section. This is discussed further in the Sedimentation section. About seven feet of scour is evident at the mouth but this decreases upstream. The highest upstream cross-section surveyed at South Jackson Street shows no change in the profile since 1986.





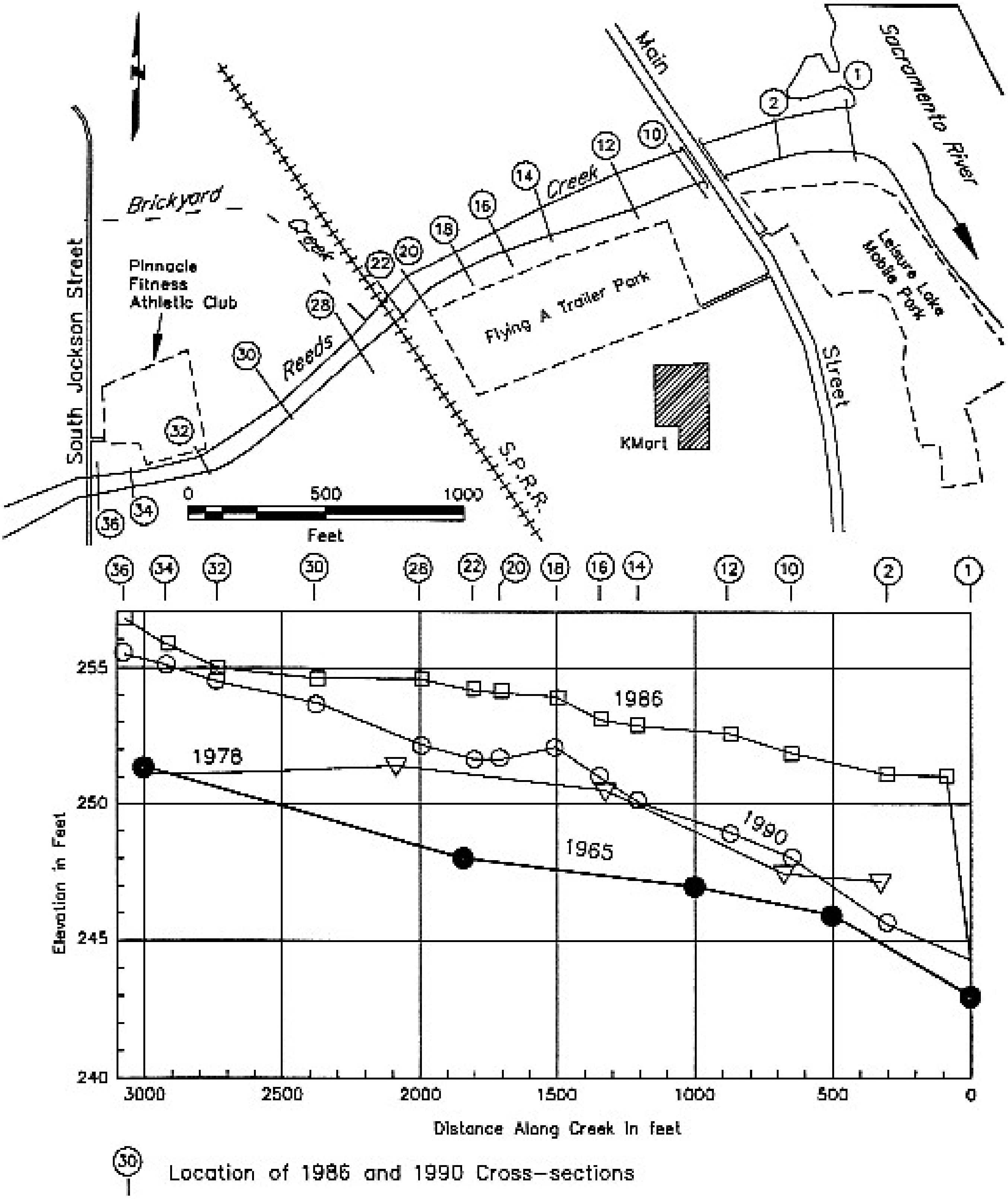
Note: Elevations are from surveyed benchmarks; Heights are from temporary benchmarks established at the bridge.

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN DISTRICT

Sacramento Valley Westside Tributary Watersheds Erosion Study

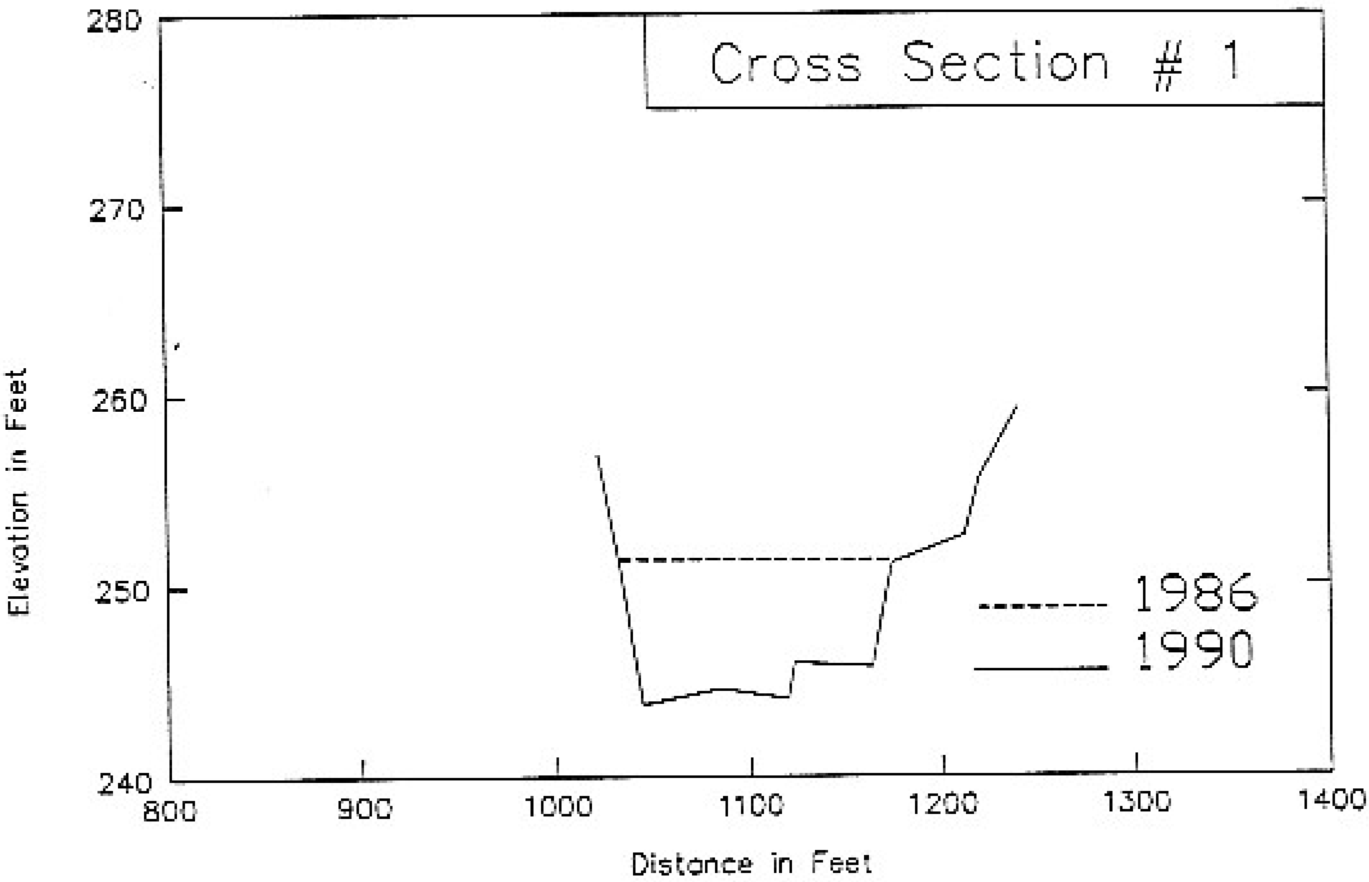
Reeds Creek Bridge Cross-Sections

October 1991

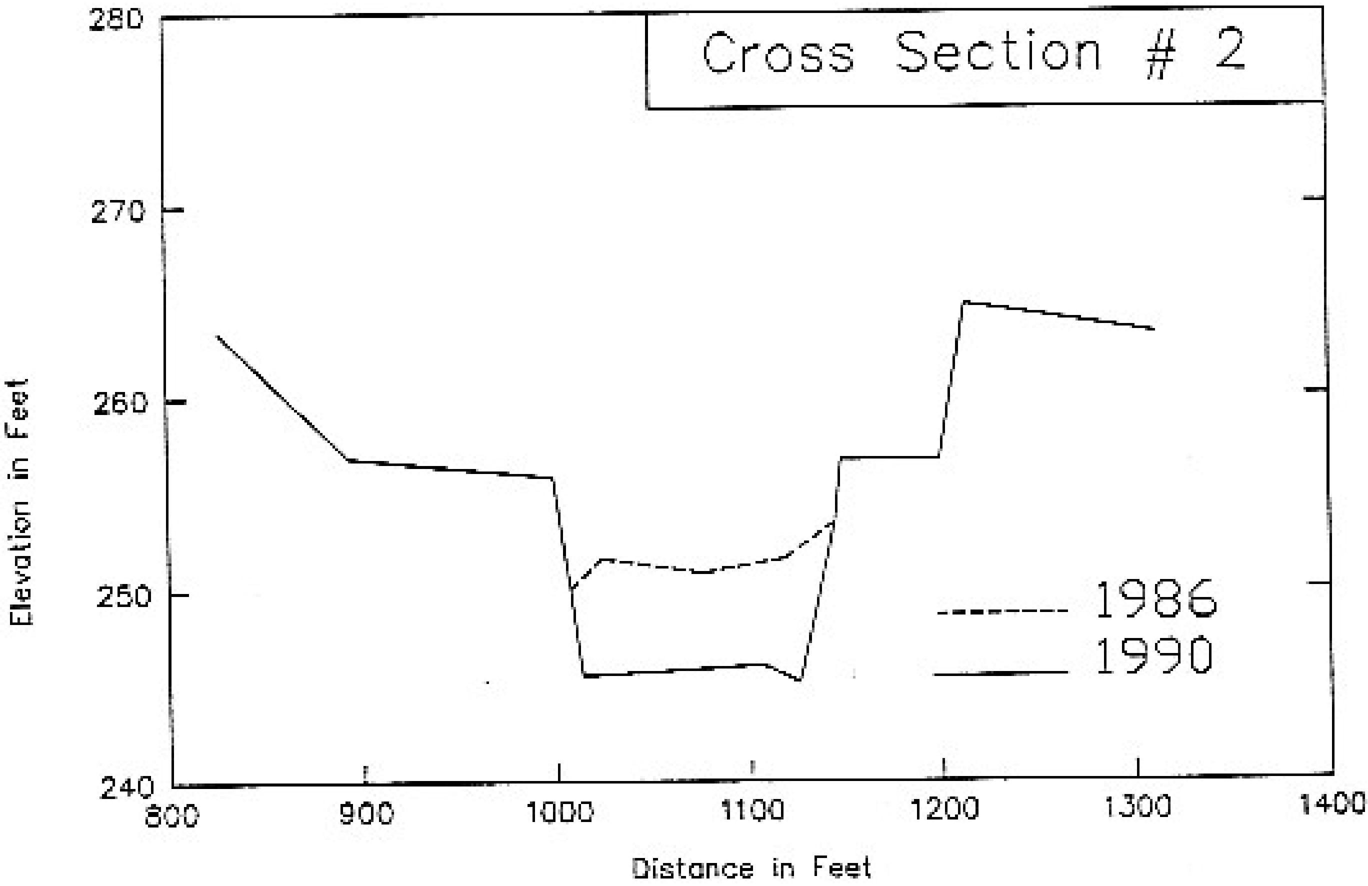


Sacramento Valley
Westside Tributary Watersheds
Erosion Study
Changes in the Stream Profile
Reeds Creek

Figure 10



Cross Section # 1
280
270
260
250
240
Elevation in Feet
800
900
1000
1100
1200
1300
1400
Distance in Feet
1986
1990



Cross Section # 2
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270
260
250
240
Elevation in Feet
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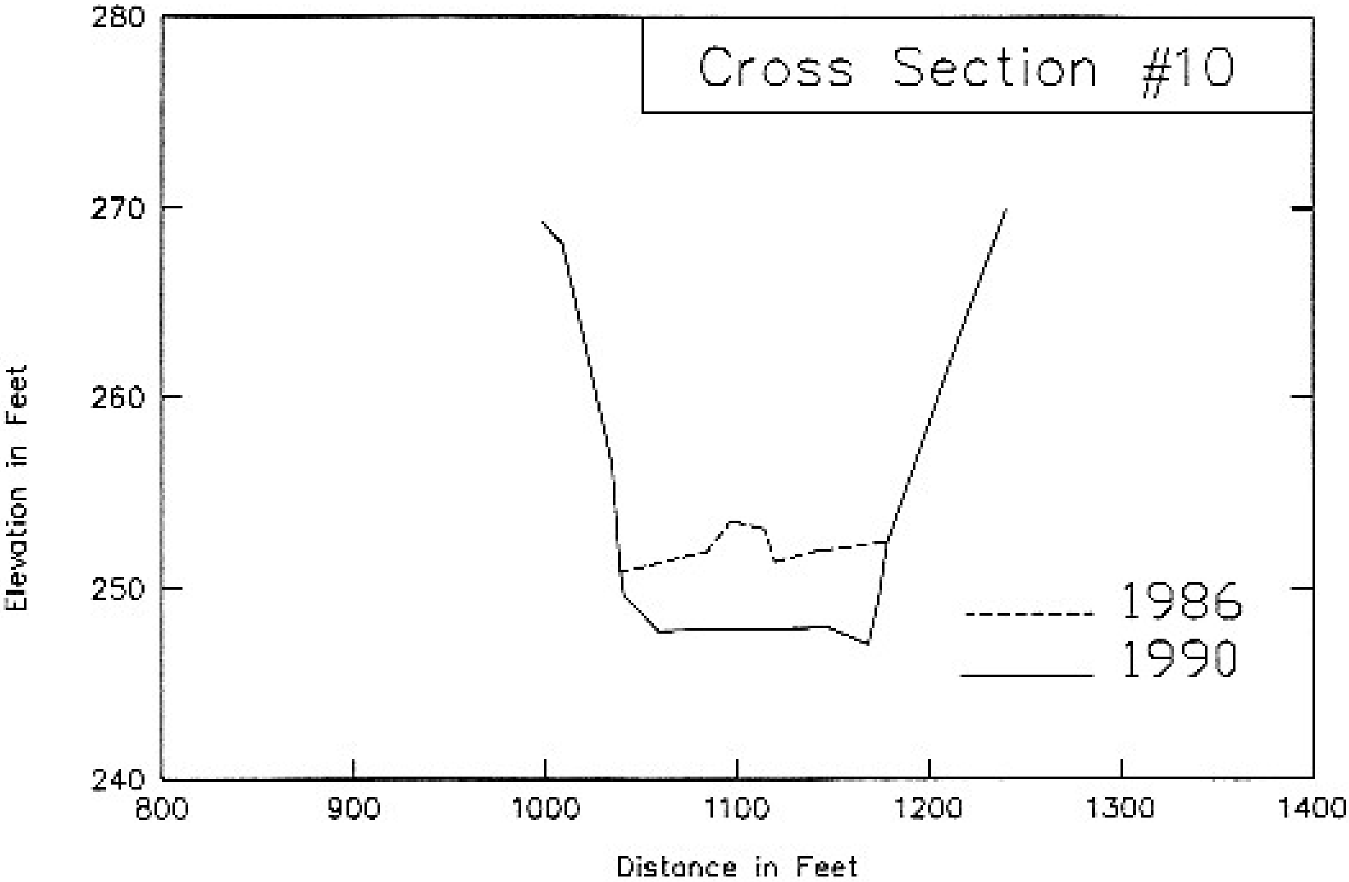
900
1000
1100
1200
1300
1400
Distance in Feet
1986
1990


Cross Section #10
Elevation in Feet
Distance in Feet
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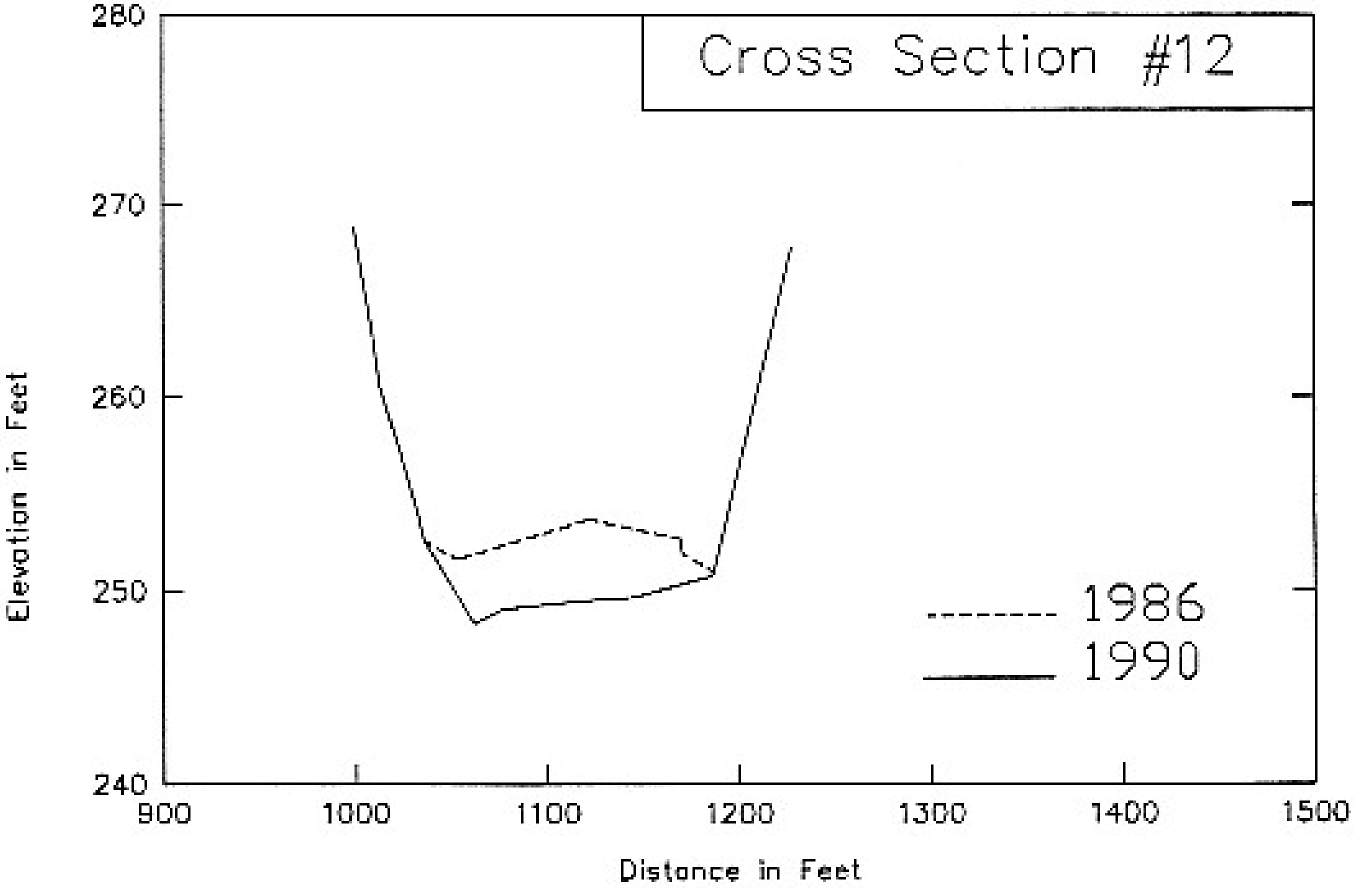
270
260
250
240
800
900
1000
1100
1200
1300
1400
1986
1990


Cross Section #12
Elevation in Feet
Distance in Feet
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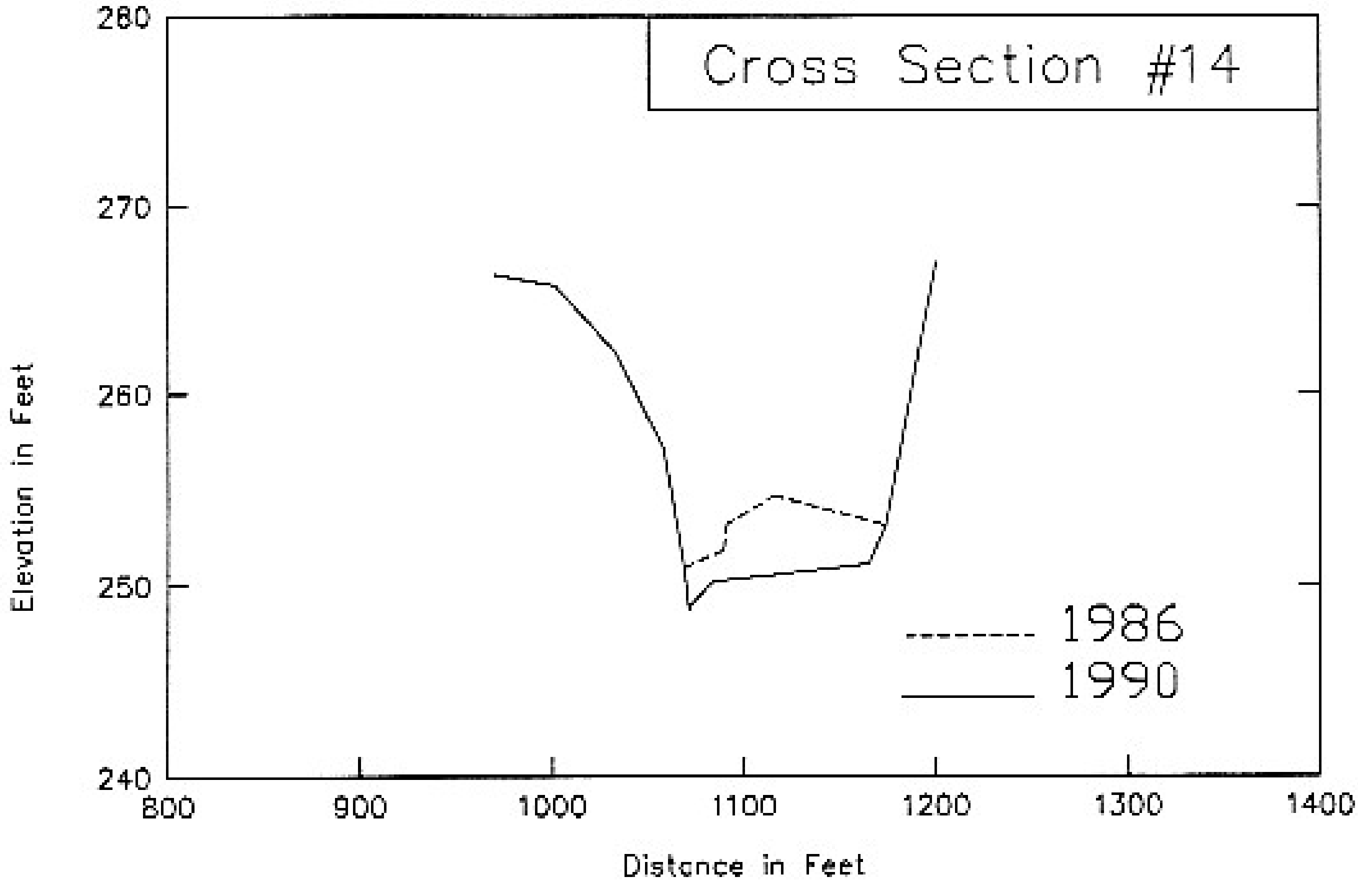
270
260
250
240
900
1000
1100
1200
1300
1400
1500
1986
1990


Cross Section #14
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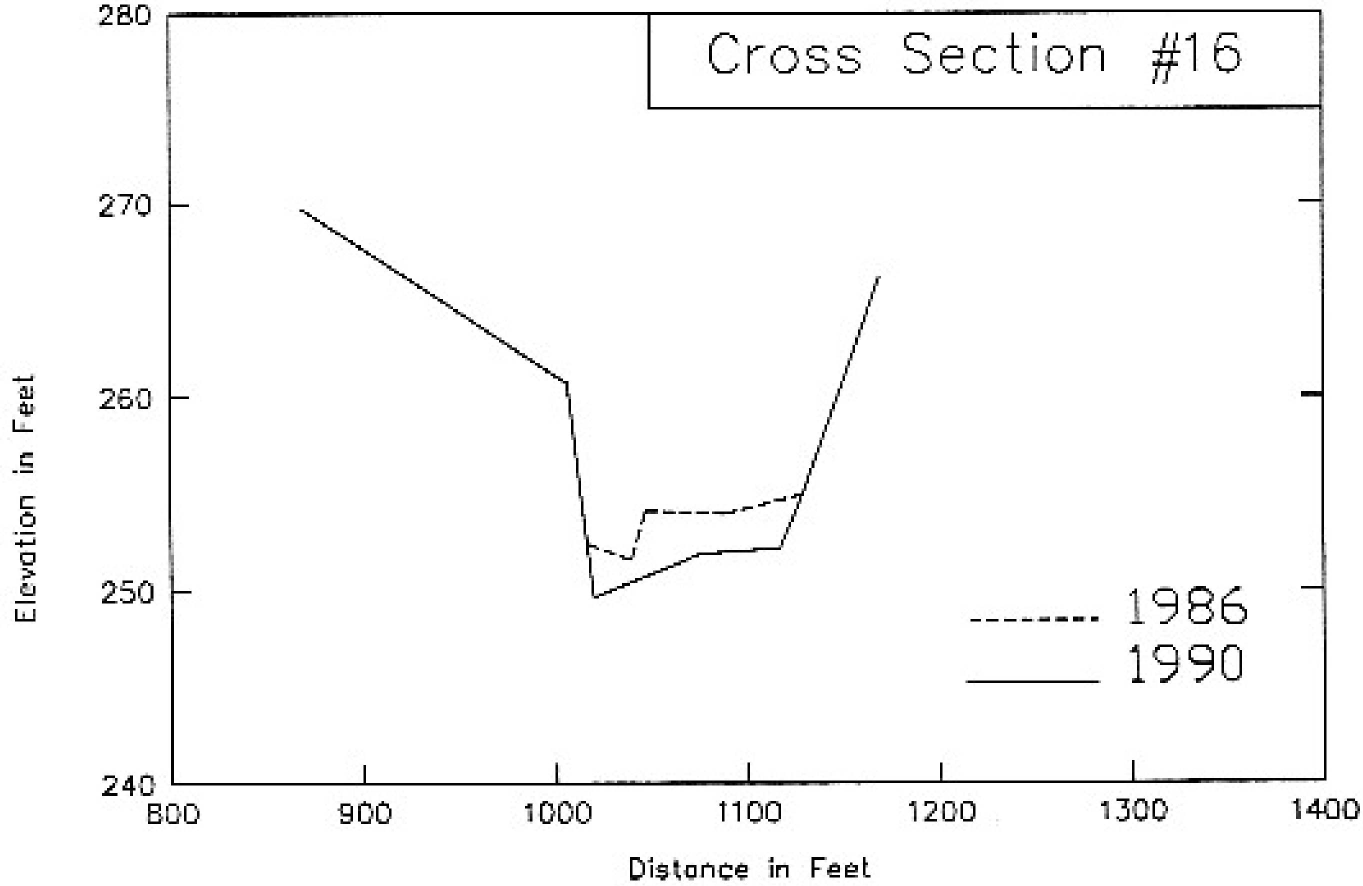
270
260
250
240
Elevation in Feet
800
900
1000
1100
1200
1300
1400
Distance in Feet
1986
1990


Cross Section #16
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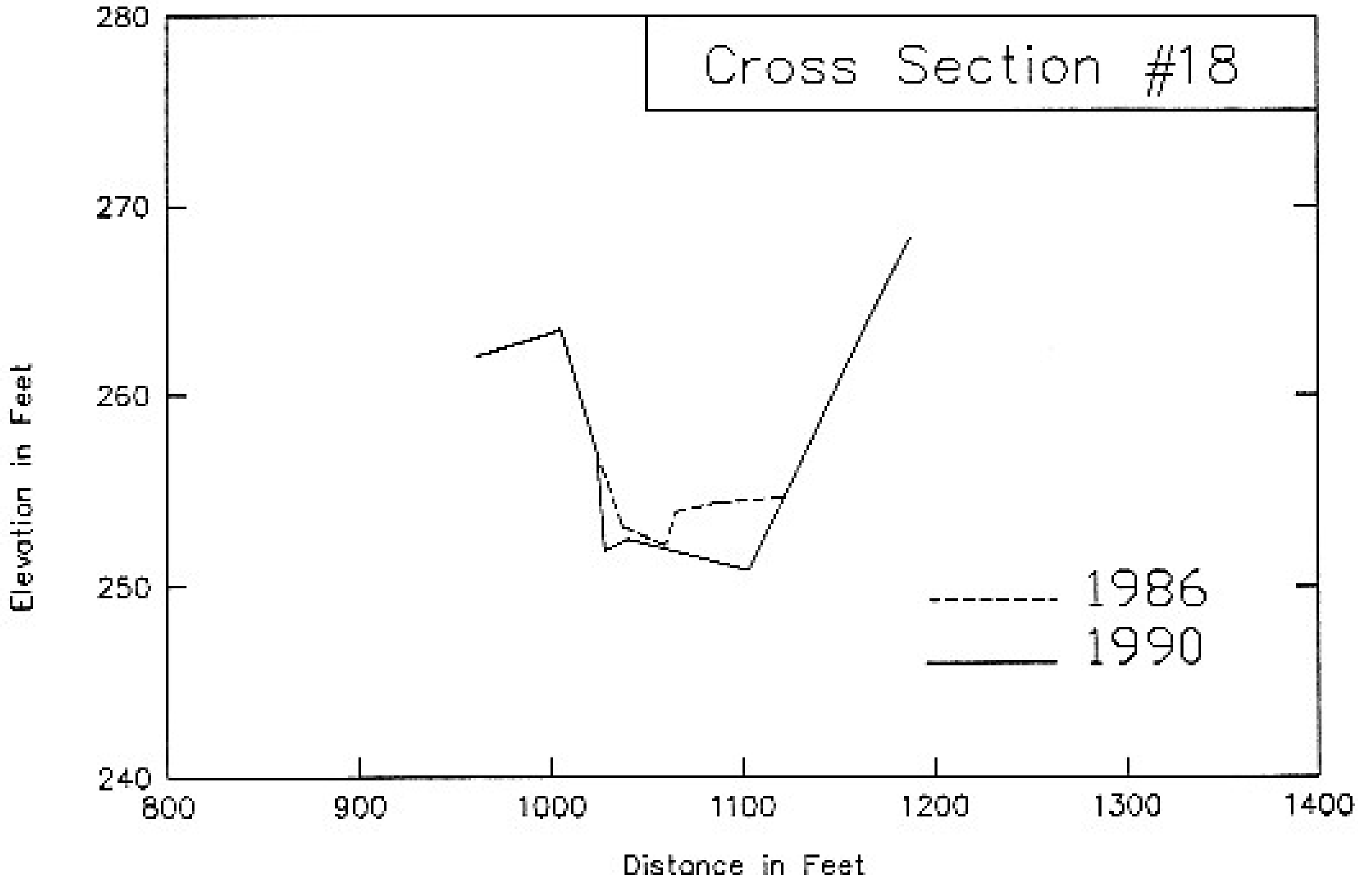
270
260
250
240
Elevation in Feet
800
900
1000
1100
1200
1300
1400
Distance in Feet
1986
1990


Cross Section #18
Elevation in Feet
Distance in Feet
1986
1990
280
270
260
250
240
800
900
1000
1100
1200
1300
1400

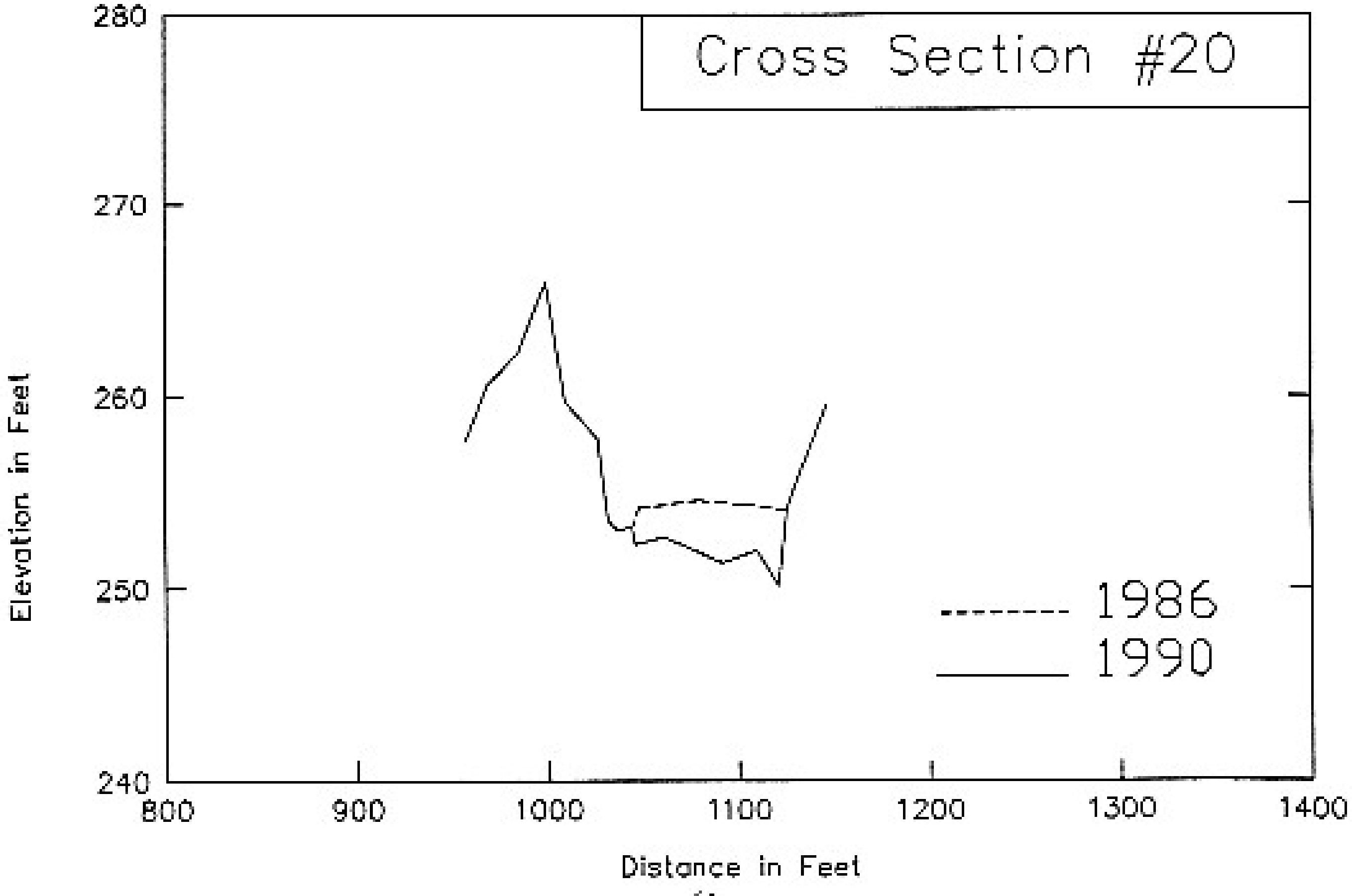
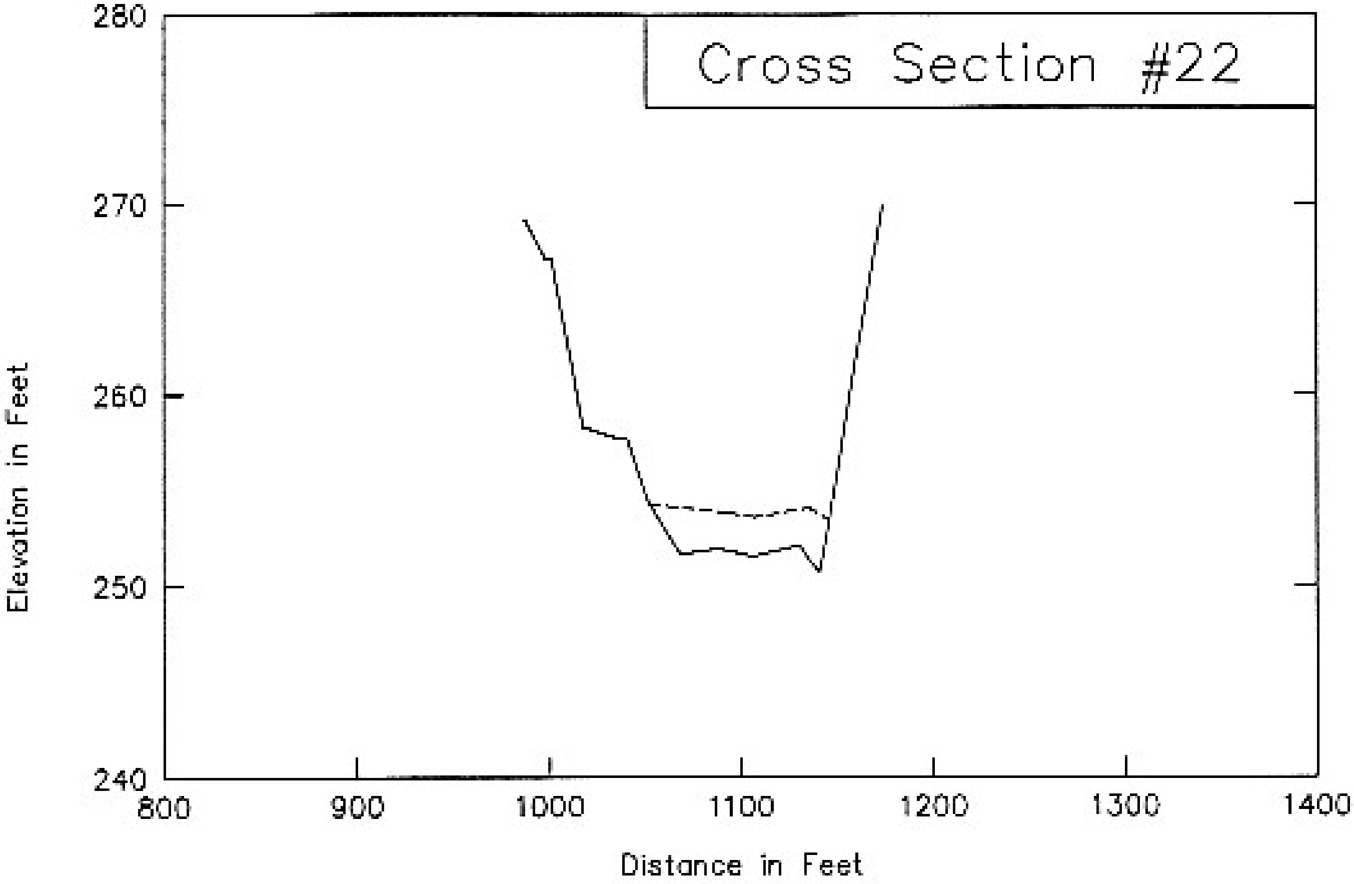

Cross Section #20
Elevation in Feet
Distance in Feet
1986
1990
280
270
260
250
240
800
900
1000
1100
1200
1300
1400

Figure 14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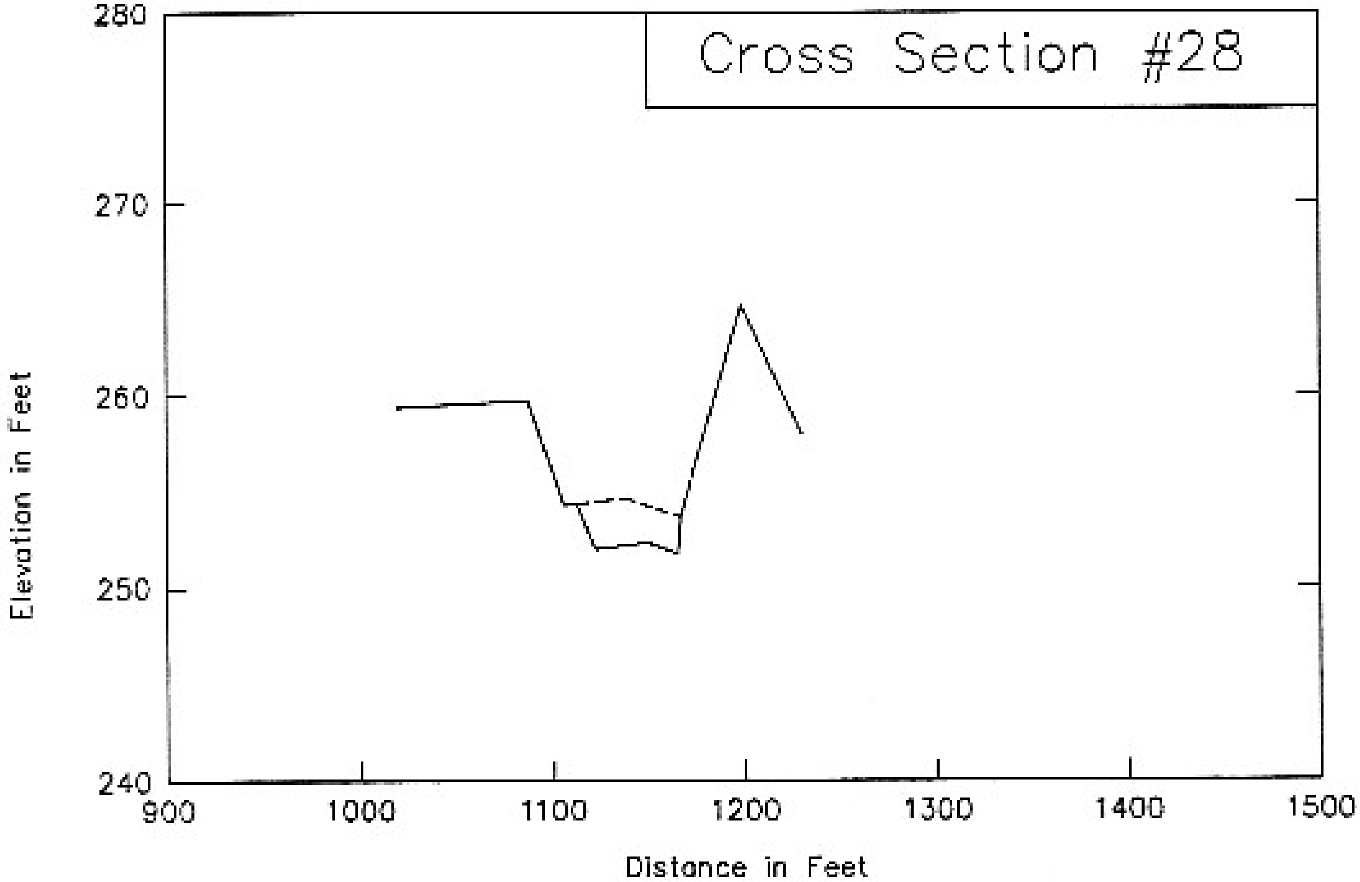
270
260
250
240
Elevation in Feet
800
900
1000
1100
1200
1300
1400
Distance in Feet


Cross Section #28
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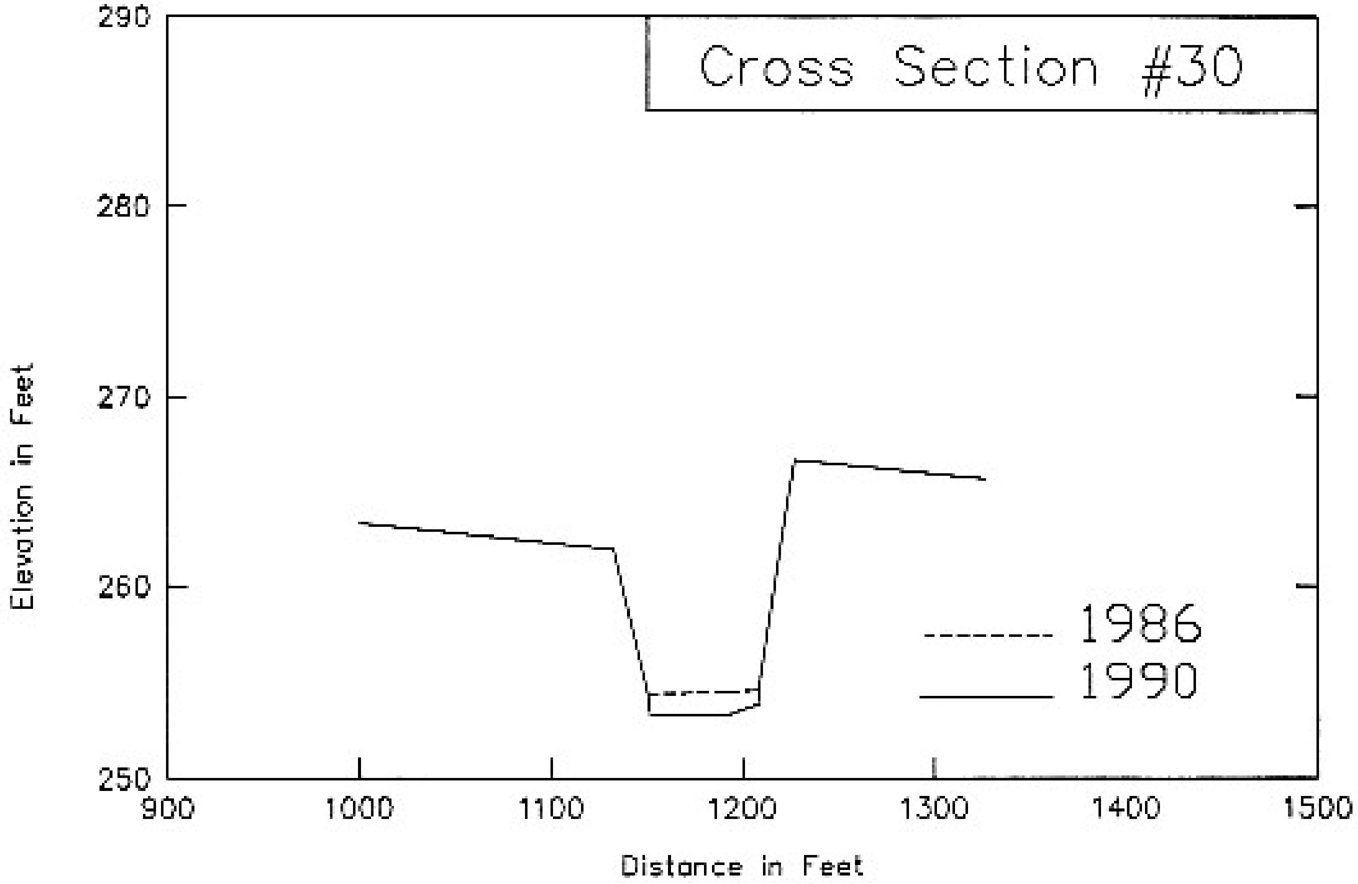
270
260
250
240
Elevation in Feet
900
1000
1100
1200
1300
1400
1500
Distance in Feet


Cross Section #30
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280
270
260
250
900
1000
1100
1200
1300
1400
1500
Elevation in Feet
Distance in Feet
1986
1990

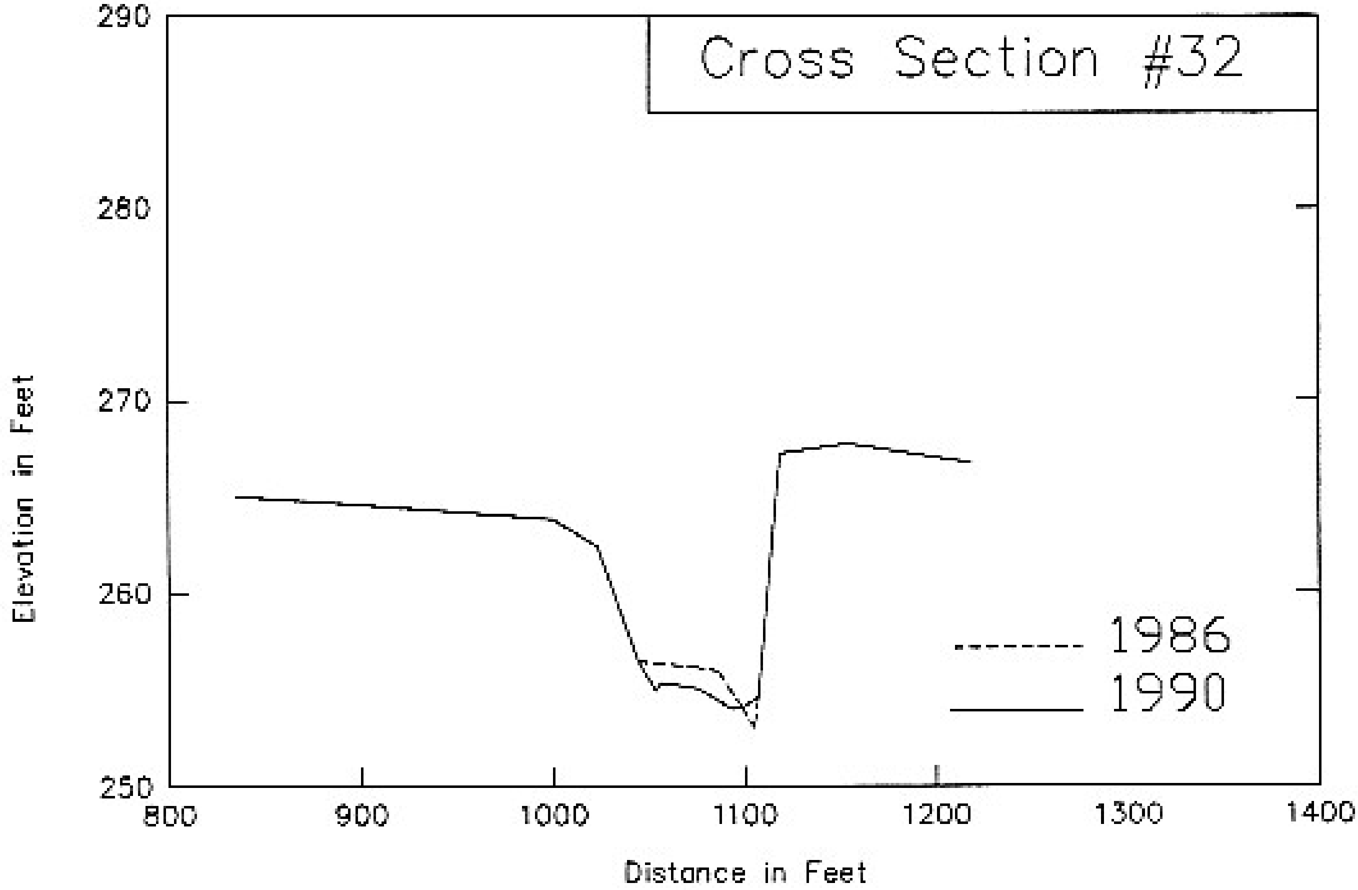
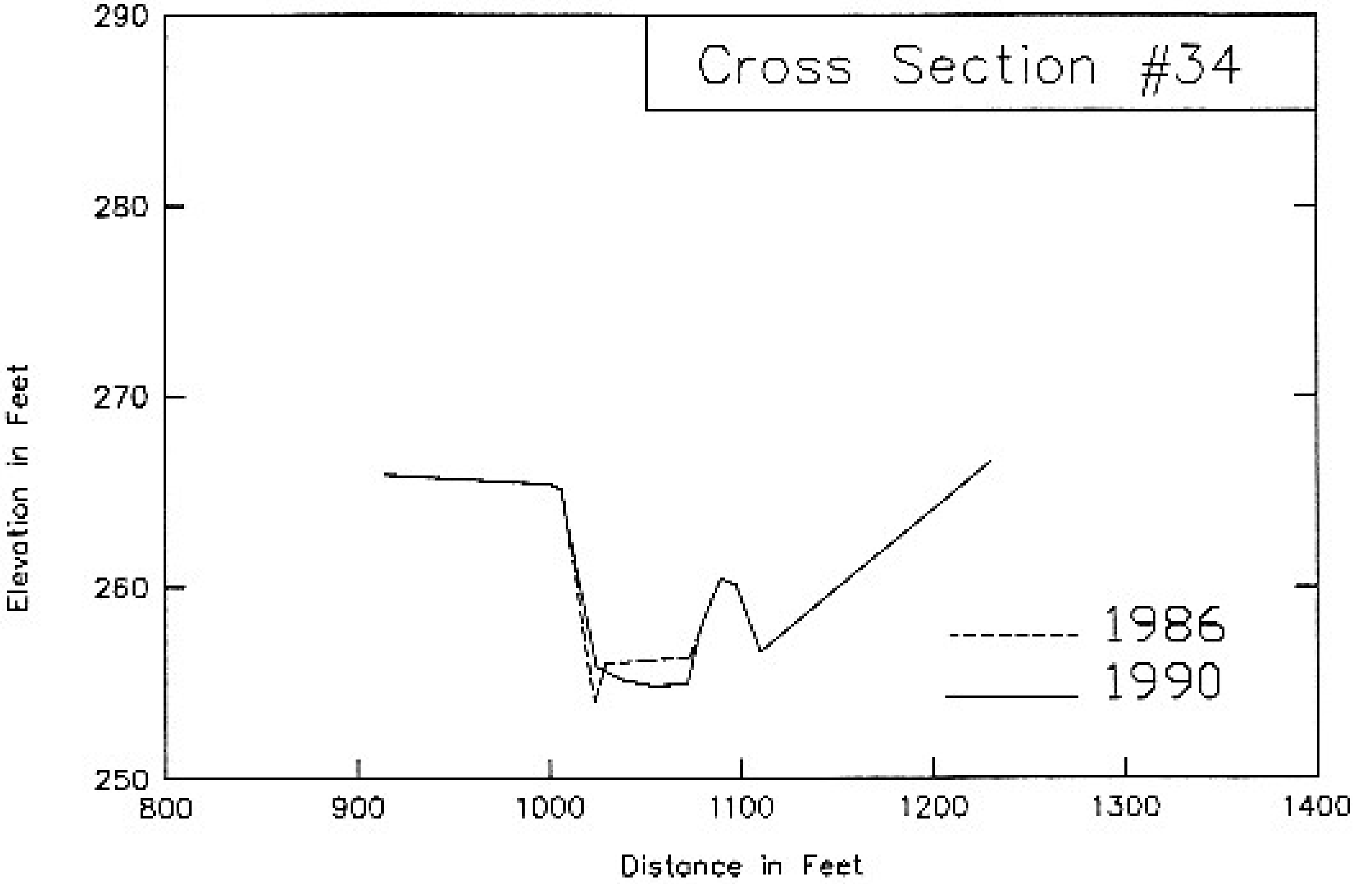

Cross Section #32
290
280
270
260
250
800
900
1000
1100
1200
1300
1400
Elevation in Feet
Distance in Feet
1986
1990

Figure 16


Cross Section #34
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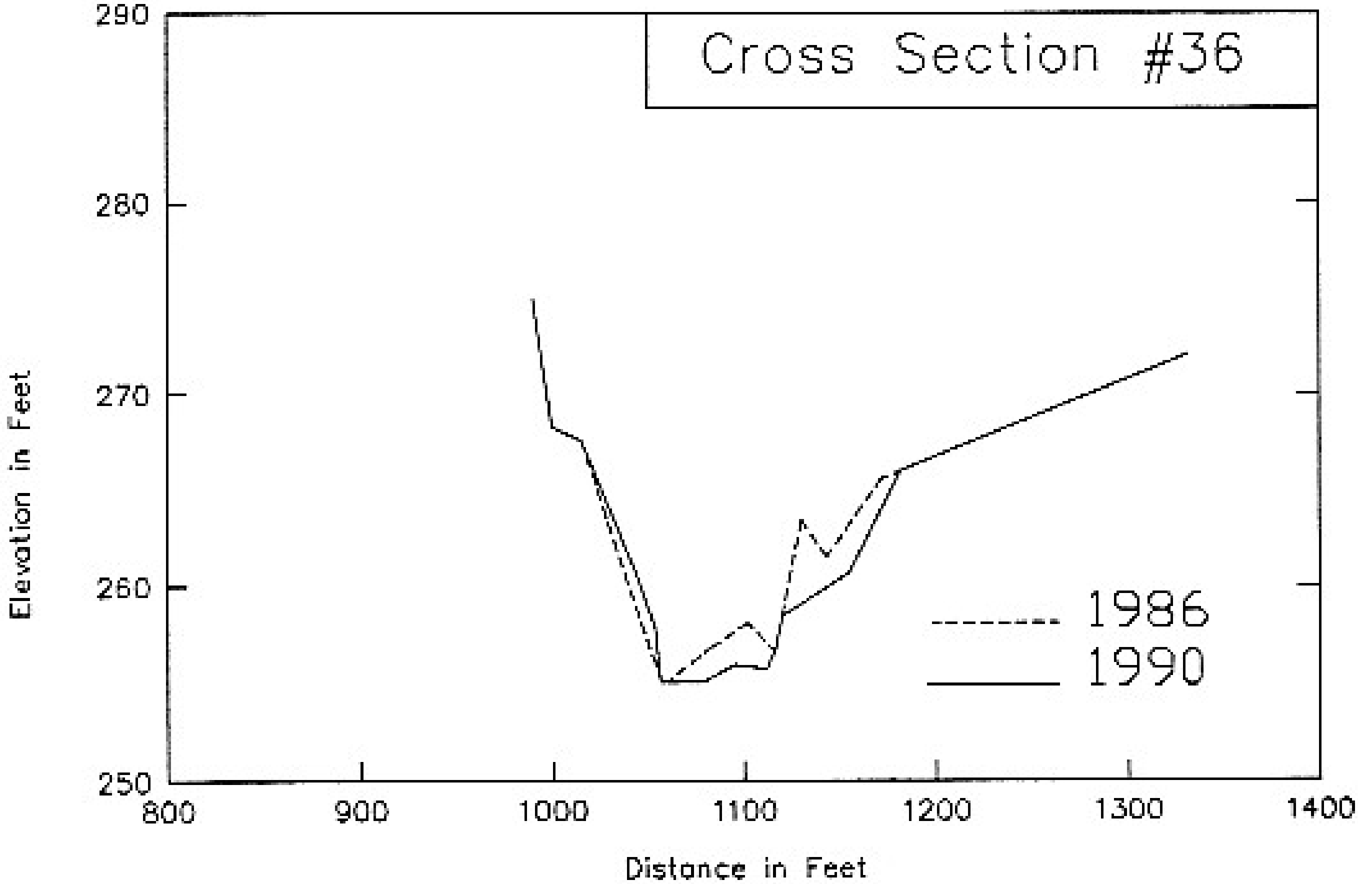
280
270
260
250
Elevation in Feet
1986
1990
800
900
1000
1100
1200
1300
1400
Distance in Feet


Cross Section #36
290
280
270
260
250
Elevation in Feet
1986
1990
800
900
1000
1100
1200
1300
1400
Distance in Feet

TURBIDITY

Turbidity is an optical property attributable to suspended and colloidal matter, which disturbs water clarity and reduces the penetration of light. High and persistent turbidities are indicators of unstable or erodible geologic units, poor land use practices, or both. High turbidities can be used to locate problem areas in the watershed. Silt, clay, finely divided organic matter, and algae are causes of turbidity. Most of the turbidity occurs during high flows in winter months. The rising part of the storm hydrograph is generally more turbid than the same magnitude receding flow.

Sampling Program

In the early part of 1986, DWR made seven turbidity sampling runs in the Reeds Creek basin. Each run consisted of collecting about 20 water samples at selected stations of the watershed during the rising and falling stages over a three-hour period. Samples were collected at each location shown on Figure 17.

Turbidity samples were collected at various times during a particular storm sequence. Some were collected during the rising limb of the storm hydrograph, some during the receding limb, and some after the storm. Samples were stored in plastic bottles and analyzed in the laboratory using a Hach Laboratory Model 2100A turbidimeter. The turbidimeter measures in Nephelometer Turbidity Units (NTUs), with 10 NTUs the maximum allowable for drinking water and 30 NTUs the limit of fishability.

Sampling Results & Analysis

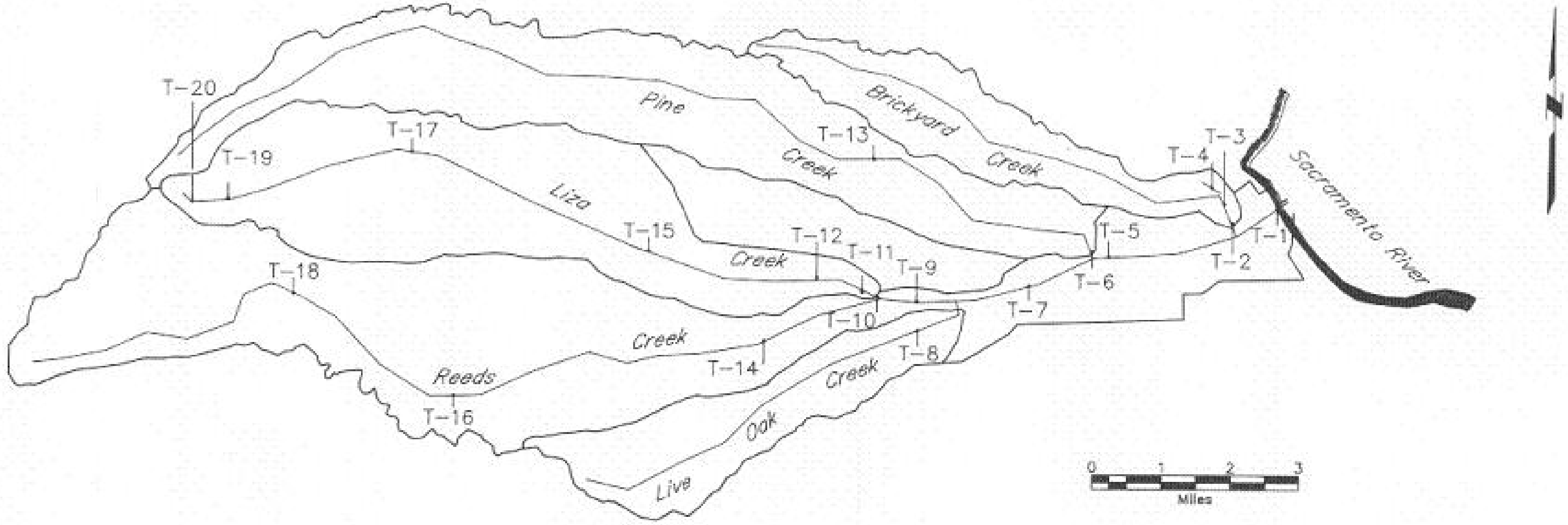
Our turbidity sampling has shown that turbidity within the basin increases in response to specific land uses. In 1986, concentrated cattle feeding in a portion of the Pine Creek sub-basin produced runoff with turbidity readings in excess of 2,000 NTUs. Brickyard Creek has produced turbidities in excess of 2300 NTUs. This may be in response to the intense Off-road recreational vehicles (ORV) use near the County landfill and urban development within the sub-basin.

Of the seven turbidity runs made during the early months of 1986, the highest recorded turbidity in the watershed was 2,320 NTUs near the mouth of Brickyard Creek on February 2, 1986. Figure 17 shows the sampling results. The mouth of Reeds Creek (T1) had the highest average turbidity of all the stations. Liza Creek (T10) was second; it was generally higher than Reeds Creek above its confluence, and other tributaries. A small tributary of Liza Creek, herein called Owens Creek (T15), had the highest overall turbidity on two of the seven sampling runs. Overall, a small tributary we named the South Fork Liza Creek had the lowest recorded turbidities.

In general, the measured turbidity increases downstream except when influenced by local cloud bursts. Except for the samples from January 31, 1986, this trend is obvious. On that date a cloud burst occurred in the upper watershed, but the flow had not reached the lower sampling sites.

Some of the lowest recorded turbidities occurred in the upper parts of the drainage system. This includes a small tributary in the upper watershed of Reeds Creek, South Fork Liza Creek (T11), upper Reeds Creek (T14), Brush Creek (T7), and upper Liza Creek. Overall, South Fork Liza Creek had the lowest turbidities.

Figure 17



STATIONS	LOCATION	1/31/86	2/2/86	2/3/86	2/14/86	2/16/86
T-1	REEDS CREEK @ MAIN ST. BRIDGE	185	2160	860	670	411
T-2	BRICKYARD CREEK @ WALNUT ST.	228	2320	310	378/395	135
T-3	BRICKYARD CREEK @ BAKER RD.	132	1910	315	400/410	130
T-4	N.F. BRICKYARD CREEK @ STOLL RD.	485	N.R.	156	465/463	87
T-5	REEDS CREEK @ WILDER RD.	790	1240	730	660	387
T-6	PINE CREEK @ REEDS CREEK RD.	430	N.R.	345	415	190
T-7	BRUSH CREEK @ REEDS CREEK RD.	210	880	325	365	96
T-8	LIVE OAK CREEK @ WILLARD RD.	700	570	260	620	80
T-9	REEDS CREEK @ WILLARD RD.	1380	N.R.	640	840/856	350
T-10	LIZA CREEK @ REEDS CREEK RD.	1540	740	880	795	285
T-11	S.F. LIZA CREEK @ REEDS CREEK RD.	320	365	470	210/212	52
T-12	LIZA CREEK @ BRIDGE CROSSING	1260	?	435	N.R.	192
T-13	PINE CREEK @ PINE CREEK RD.	430	390	N.R.	N.R.	N.R.
T-14	N.F. REEDS CREEK @ JOHNSON RD.	790	N.R.	430	326	128
T-15	OWENS CREEK @ REEDS CREEK RD.	830	N.R.	390	2000	174
T-16	REEDS CREEK @ HESS RD.	620	N.R.	118	544	146
T-17	LIZA CREEK @ OWENS RD.	840	N.R.	N.R.	776	154
T-18	REEDS CREEK @ MASTEN RD.	300	108	72	304	67
T-19	LIZA CREEK @ REEDS CREEK RD. BELOW MASTEN RD.	212	N.R.	63	584	91
T-20	LIZA CREEK @ MASTEN RD.	N.R.	N.R.	N.R.	336	52

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN DISTRICT

Sacramento Valley
Westside Tributary Watersheds
Erosion Study

Reeds Creek Watershed
Stream Turbidity

October 1991

EROSION AND INSTABILITY

The term "accelerated erosion" means loss of soil at rates greater than geologic rates due to human activities. The most common cause of accelerated erosion in this watershed is vegetative cover damage resulting from livestock grazing. Other contributors to accelerated erosion include cultivation, wildfires, oak harvesting, urbanization, and roads. All of these factors have historically impacted the vegetative cover in the Reeds Creek watershed and overlap to form the patterns seen today.

A study by the Soil Conservation Service (SCS, 1979) quantified non-point sources of erosion and sedimentation in the adjacent Red Bank Creek basin. The study showed that sheet and rill erosion is the dominant form of sediment production. The rates developed from the Universal Soil Loss Equation (USLE) and monitored points are directly applicable to the Reeds Creek watershed. Sheet and rill erosion produces 560 tons/square mile/year from this type of soil under the same type of local climate, slope and aspect in the Red Bank Creek drainage. Total sediment yield was 750 tons/square mile/year.

However, land use may be more intense in the Reeds Creek drainage. The deforested land that covers 80 percent of the basin probably has higher raindrop intensities than adjacent oak woodland. This lack of cover results in more sediment in suspension per acre. As gullies develop into incised streams and work their way headward, the flow efficiency of the runoff is increased. This moves water at higher velocity into the stream channel system that drains the area, resulting in higher and more pronounced peaks.

The two main slope processes active in the basin are sheet and rill erosion and headward erosion along first order streams. Steep, non-vegetated stream banks and gullies occur throughout the watershed (photo 12). However, many of the gullies show evidence of having been more active in the past. Natural infilling, smoothing of the interior slopes and reestablishment of vegetation suggests that some of the gullies have been partially stabilized following a period of intense cultivation or overgrazing. Other gullies are active with bare, rilled head and side slopes. Notable examples of actively eroding, rilled slopes occur in the Brickyard Creek drainage and along one linear valley in Section 15 (see Plate 4) between Pine Creek and Liza Creek. Some of these areas occur in the vicinity of heavy off road vehicle use or adjacent to private roads along ridge tops.

Another major sediment source found during this investigation is the unvegetated stream side slopes and channels. These slopes tend to dry ravel during the summer and develop an accumulation of material near their bases by fall. The first runoff of the year mobilizes this material and causes a highly, turbid "flush" of the system. Subsequent storms will move material into the channel by sheet and rill erosion on the less steep slopes. On near vertical slopes, material is moved to the channel by block failures along joint planes.

Photo 12. Gully formation is generally increased in areas that are cultivated, overgrazed or converted from oak woodland.

Pine Creek has many first order streams feeding the main trunk and the majority of the 30-50 percent slopes within the Reeds Creek basin. These two factors result in the highest sediment carrying capacity of all the tributaries.

Landslides are not a big source of sediment yield in this basin. The low percentage of landslides suggests that slope instability is rare and seasonal (photo 13).

Most of the landslides examined from the road appear to be earth flows or shallow slumps. In some cases they have been aggravated by multiple livestock trails that parallel the slope. A typical landslide shape is linear, 150 feet long by 30 feet wide with irregular, hummocky topography. Most landslides occur at mid-slope and often do not reach all the way to the base of the slope. This type of slope failure represents a minor sediment source within the watershed. One large area of multiple slides occurs along the north side of Brickyard Creek (see Plate 4).

Road maintenance contributes to erosion during annual cleaning of drainage ditches. In cases where the cut slope is unstable, the grader work may actually undercut the toe support for the slope and aggravate the continued slippage or raveling of the unvegetated cut slopes along roads.

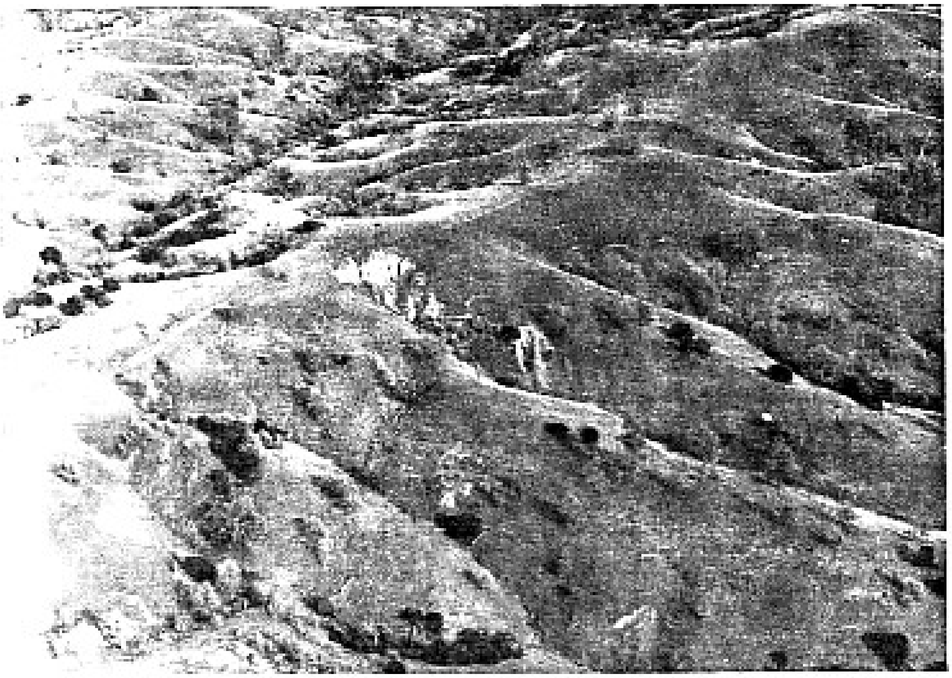


Photo 13. Landslides occur in localized areas in the upper watershed. Tree removal increases the likelihood of landsliding because of loss of root support.

SEDIMENTATION

Several reports have dealt with sediment yields from westside streams. The U. S. Geological Survey (1972) estimated the yield from Red Bank Creek to be 300+ tons per square mile. Using the same yield for Reeds Creek produces a total of 22,500 tons per year for the basin. The average percent of bedload is about 6 percent of the total load, or 1350 tons per year.

In 1979, the U.S. Department of Agriculture estimated that Red Bank Creek produced 723 tons per square mile per year. Using the same figure for Reeds Creek would yield about 54,000 tons of total load for the basin. Six percent of that would be about 3300 tons.

DWR (1984) calculated the bedload using the Myer-Peter and Muller equation based on a comparison with Red Bank Creek. The results indicate that 2,200 tons per year of one-half inch and larger gravel, and 16,000 tons of bedload, are produced each year.

A rough bedload estimate can be calculated from the Department's 1987 report. The Red Bluff Diversion Dam was closed in 1967. Between 1967 and 1986, Reed's Creek aggraded because of backwater effects. The deposition is a conservative estimate of the amount of bedload. The estimate is made using invert profiles, average cross-sectional widths and the number of years between surveys. These calculations yield a yearly average of about 4,300 cubic yards between 1967 and 1986. This estimate is low because some of the finer bedload did not deposit in the reach. The long-term sediment yield may also be different because of changing watershed and hydrologic conditions.

The Reeds Creek channel section at Main Street is within the normal pool elevation influence of the Red Bluff Diversion Dam (253 feet). The diversion dam was first closed in 1967. The gates were used to maintain the normal pool elevation except when flows exceeded 55,000 cubic feet per second. Beginning in 1986, the gates were continuously open from October to March. Sedimentation in the lower reach of Reeds Creek is highly influenced by the dynamic conditions in this backwater area.

In March 1990, fourteen cross-sections established during the 1987 Reeds Creek Flood Study were re-surveyed. They show that, since the dam began opening its gates during the winter, approximately 35,000 cu yards of gravel has been flushed out of this section. The effect on the channel thalweg is shown in Figure 9 and photographs 6 and 7. About seven feet of scour is evident at the mouth but this decreases upstream. The highest upstream cross-section surveyed at South Jackson Street shows no change in the profile since 1986.

DWR estimated the long-term geologic erosion by measuring the total amount of erosion occurring since the formation of the Red Bluff pediment 450,000 years ago. This calculation yields about 25,000 tons/per year. Assuming that the age of the Red Bluff pediment is fairly accurate, this would indicate that present erosion rates are from 1.5 to 2 times the geologic rates.

BIBLIOGRAPHY

Barbour, M. G. "Community Ecology and Distribution of California Hardwood Forests and Woodlands." *General Technical Report PSW-100.* U.S.F.S., U.S. Department of Agriculture, pp. 18-25. 1987.

Bartolome, et al., "Natural Regeneration of California Hardwoods." *General Technical Report PSW-100.* U.S.F.S., U.S. Department of Agriculture, pp. 26-31. 1987.

Bolsinger, C. L., (In Press), in Bartolome, J. W., et al. "Natural Regeneration of California Hardwoods." *General Technical Report PSW-100.* U.S.F.S., U.S. Department of Agriculture, pp. 26-31. 1987.

California Department of Forestry. *California's Forests and Rangelands: Growing Conflict Over Changing Uses.* Forest and Rangeland Resources Assessment Program. Sacramento, CA. 148 p. 1988.

California Department of Water Resources. *Upper Sacramento River Spawning Gravel Study.* District Report. 1980.

______. *Middle Sacramento River Spawning Gravel Study.* District Report. August 1984.

______. *Reeds Creek Flood Study.* District Report. December 1987.

California Division of Mines and Geology. *Geologic Map of California.* Compiled by C. W. Jennings. 1977.

Cockerham, R. S. *Evidence for a 180-KM-Long Subducted Slab Beneath Northern California.* Bulletin of the Seismological Society of the America, Vol. 74, No. 2, pp. 569-576. 1984.

DeLasaux, M. J., and N. H. Pillsbury. "Site Index and Yield Equations for Blue Oak and Coast Live Oak." *General Technical Report PSW-100.* U.S.F.S., U.S. Department of Agriculture, pp. 325-334. 1987.

Doak, S., and B. Stewart. "A model of economic forces affecting California's hardwood Resource: monitoring and policy implications." Unpublished report.

Earth Sciences Associates (ESA). *Seismic and Fault Activity Study-Proposed Glenn Reservoir Complex.* Prepared for California Department of Water Resources. 1980.

Federal Emergency Management Agency (FEMA). *Flood Insurance Study-City of Red Bluff, California.* March 1986.

Goodridge, J. D. "Isohyetal Map from the files of the Department of Water Resources." Unpublished. 1966.

Harwood, D. S., and E. J. Helley. *Preliminary Structure Contour Map of the Sacramento Valley, California, Showing Contours of Major Structural Features and Depth Basement.* U.S. Geological Survey Open-File Report 82-737, scale 1:250,000. 1982.

Harwood, D. S., and E. J. Helley. *Late Cenozoic Tectonism of the Sacramento Valley, California.* U. S. Geological Survey Professional Paper 1359, 46 p. 1987.

Hill-Harned & Associates. *Foundation Report for Reeds Creek Bridge Located on Paskenta Road in Red Bluff, California.* Report for Tehama County Road Department, Gerber, California. January 1973.

Jones & Stokes Associates. *Hardwood, Rangeland, Soil, and Water Quality in California: Resource Assessment and Management.* Prepared for the California Department of Forestry, Report No. JSA 88-012. May 1991.

Jones, B. L., N. L. Hawley, and J.R. Crippen. *Sediment Transport in the Western Tributaries of the Sacramento River, California.* U. S. Geological Survey WSP 1798-J. 1972.

Ingersoll, R. V. "Petrofacies and Provenance of Late Mesozoic Forearc Basin, Northern and Central California." *The American Association of Petroleum Geologists Bulletin.* Vol. 67, No. 7, July, pp. 1125-1142. 1983.

______. "A Plate-Tectonic Model for Late Jurassic Ophiolite Genesis, Nevadan Orogeny and Forearc Initiation, Northern California." *Tectonics.* Vol.5, No. 6, October, pp. 901-912. 1986.

Kay, B. L. "Long-Term Effects of Blue Oak Removal on Forage Production, Forage Quality, Soil, and Oak Regeneration." *General Technical Report PSW-100.* U.S.F.S., U.S. Department of Agriculture, pp. 351-356. 1987.

Lee, G. California Department of Forestry. "Firewood market in California." Unpublished research. Sacramento, CA. 1984.

Menke, J. W. "Hardwood Range Management." *General Technical Report PSW-100.* U.S.F.S., U.S. Department of Agriculture, 342 p. 1987.

Muick, P. C., and J. W. Bartolome. "Factors Associated with Oak Regeneration in California." *General Technical Report PSW-100.* U.S.F.S., U.S. Department of Agriculture, pp. 86-91. 1987.

Raguse, C. A. "Beef Production on Converted Foothill Oak Woodland Range in the Western Sierra Nevada." *General Technical Report PSW-100*. U.S.F.S., U.S. Department of Agriculture, pp. 361-366. 1987.

Russell, R. D. "The Tehama Formation of Northern California." Unpublished Ph.D. Thesis, Geology Dept., University of California, Berkeley. 133 p. 1931.

Stein, R. S., and R. S. Yeates. "Hidden Earthquakes." *Scientific American*. pp. 48-57. June 1989.

Suchecki, R. K. "Facies History of the Upper Jurassic-Lower Cretaceous Great Valley Sequence: Response to Structural Development of an Outer-Arc Basin." *Journal of Sedimentary Petrology*. Vol. 54, No. 1, March, pp. 170-191. 1984.

U. S. Bureau of Reclamation. *Hydrologic Analysis of Reeds Creek, Red Bluff, California.* Memorandum. July 9, 1985.

______. *Backwater and Sedimentation Study above the Red Bluff Diversion Dam.* Sacramento River Division-California. December 1970.

U. S. Geological Survey. *Mean Annual Precipitation in the California Region.* Water Resources Division. Basic Data Compilation by S. E. Rantz. Reprint 1972.

______. *Preliminary Geological Map of the Red Bluff 100,000 Quadrangle, California.* Open-File Map of 84-105. 1984.

U. S. Soil Conservation Service. *Soil Survey of Tehama County, California.* 1967.

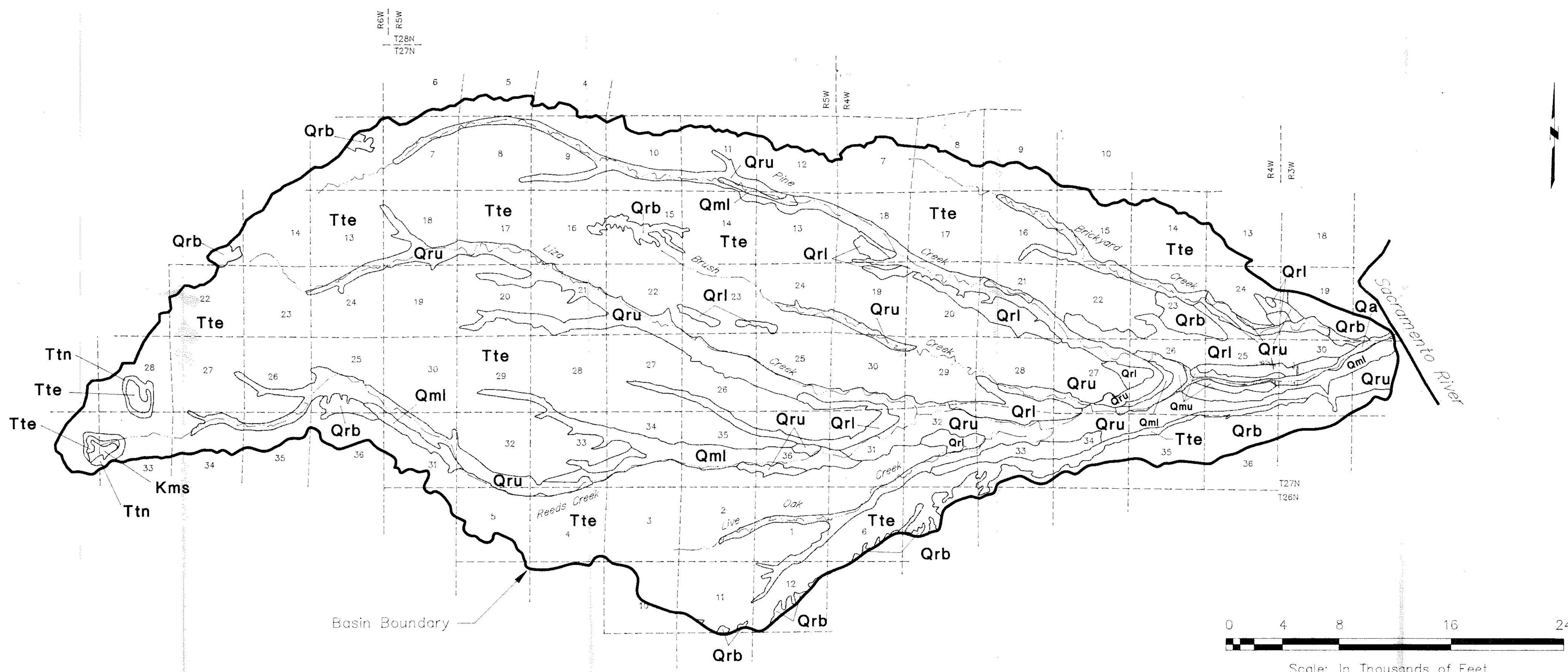
______. *Trip Report-Reeds Creek Watershed, Erosion Control.* File Code: 210-15. May 1, 1967. Update, 1979.

Walter, S. R. "Intermediate-Focus Earthquakes Associated With Gorda Plate Subduction in Northern California." *Bulletin of the Seismological Society of America*. Vol. 76, No. 2, April, pp. 583-588. 1986.

Wentworth, C. M., and M. D. Zoback. "The Style of the Late Cenozoic Deformation at the Eastern Front of the California Coast Ranges." *Journal of Tectonics*. Preliminary report. 1990.

White, K. L. "Structure and composition of foothill woodland in central coastal California." *Ecology 47*. pp 229-237. 1966.

Wong, I. G., R. W. Ely, and A. C. Kollmann. "Contemporary Seismicity and Tectonics of the Northern and Central Coast Range-Sierran Block Boundary Zone, California." *Journal of Geophysical Research*. Vol. 93, No. B7, pp. 7813-7833. July 1988.



Legend

QUATERNARY

Symbol	Description
Qa	Quaternary Alluvium
Qmu	Upper Modesto Formation
Qml	Lower Modesto Formation
Qru	Upper Riverbank Formation
Qrl	Lower Riverbank Formation
Qrb	Red Bluff Formation

TERTIARY

Symbol	Description
Tte	Tehama Formation
Ttn	Nomlaki Tuff Member

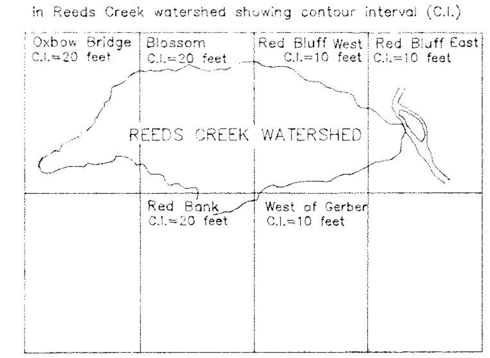
CRETACEOUS

Symbol	Description
Kms	Great Valley Sequence Mudstone

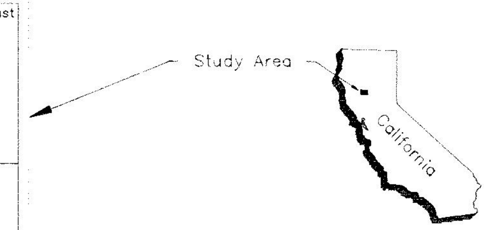
Geologic Contact

Note: Geologic mapping was modified from the U.S. Geological Survey (1984)

U.S. Geological Survey 7.5' topographic maps in Reeds Creek watershed showing contour interval (C.I.)



INDEX MAP



Location Map

STATE OF CALIFORNIA
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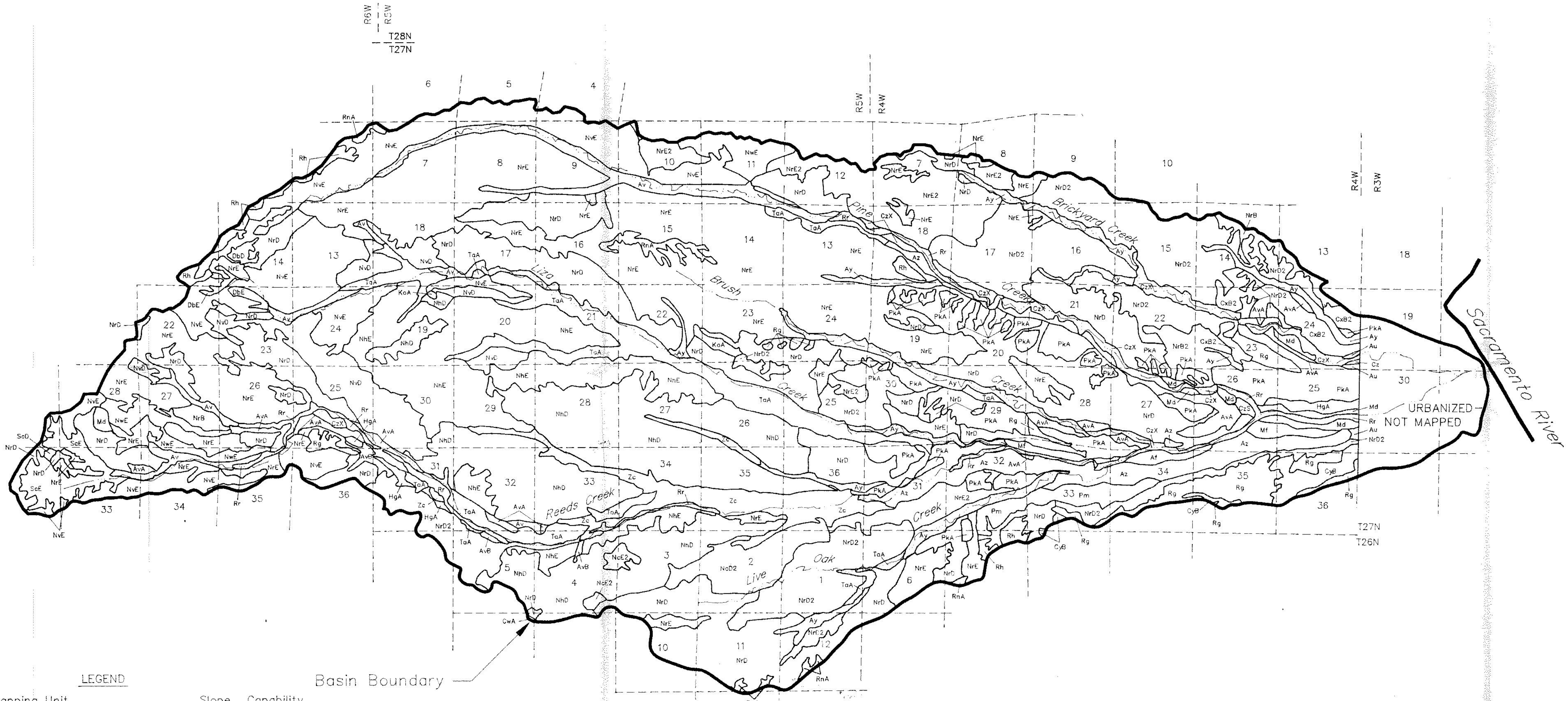
NORTHERN DISTRICT

Sacramento Valley
Westside Tributary Watersheds
Erosion Study
Reeds Creek Geology

October 1991



LEGEND

	Soil Mapping Unit	Slope	Capability
AcD	Altamont clay, terrace	10–30%	IVe–5
Af	Anita clay, moderately deep	–	IIIw–5
Au	Arbuckle gravelly fine sandy loam	0–3%	IIs–4
Av	Arbuckle gravelly loam	–	IIs–4
AvA	Arbuckle gravelly loam	0–3%	IIs–4
AvB	Arbuckle gravelly loam	3–8%	IIe–4
Ay	Arbuckle gravelly loam, channeled clay substratum	–	IIIs–3
Az	Arbuckle–Tehama complex	0–3%	IIs–3,4
CwA	Corning gravelly loam	0–3%	IVs–3
CxB2	Corning–Newville gravelly loams, eroded	3–10%	IVe–3
CyB	Corning–Redding gravelly loams	0–5%	IVe–3,IVs–8
Cz	Cortina gravelly fine sandy loam	–	IVs–4
CzS	Cortina very gravelly fine sandy loam	–	IVs–4
CzX	Cortina complex	–	VIw–1
DbD	Dibble silty clay loam	10–30%	IVe–5
DbE	Dibble silty clay loam	30–50%	VIe–5
DnE	Dibble–Newville complex	30–50%	VIe–5,3
HgA	Hillgate loam	0–3%	IIIs–3
KoA	Kimball gravelly loam	0–3%	IIIs–3
Md	Maywood fine sandy loam, moderately deep	0–3%	IIs–0
Me	Maywood loam	0–3%	I–1
Mf	Maywood loam, high terrace	0–3%	I–1
NcD2	Nacimiento Altamont complex, eroded	10–30%	IVe–5
NcE2	Nacimiento Altamont complex, eroded	30–50%	VIe–5
NhD	Nacimiento–Newville complex	10–30%	IVe–5,VIe–3
NhE	Nacimiento–Newville complex	30–50%	VIe–3,5
NrB	Newville gravelly loam	3–10%	IVe–3
NrB2	Newville gravelly loam, eroded	3–10%	IVe–3
NrD	Newville gravelly loam	10–30%	VIe–3
NrD2	Newville gravelly loam, eroded	10–30%	VIe–3
NrE	Newville gravelly loam	30–50%	VIe–3
NrE2	Newville gravelly loam, eroded	30–50%	VIe–3
NvD	Newville–Dibble complex	10–30%	IVe–5,VIe–3
NvE	Newville–Dibble complex	30–50%	VIe–3,IVe–5
NwD	Newville–Dibble complex, gullied	10–30%	VIe–3,IVe–5
NwE	Newville–Dibble complex, gullied	30–50%	VIe–3,5

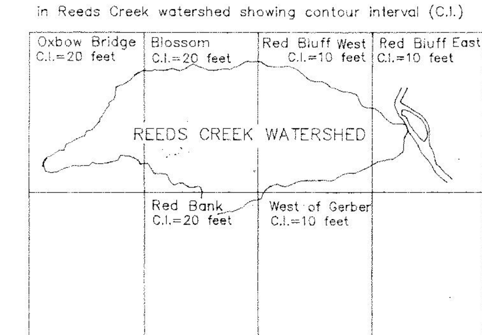
	Soil Mapping Unit	Slope	Capability
PkA	Perkins gravelly loam	0–3%	IIs–4
Pm	Perkins–Kimball gravelly loams	0–3%	IIs–4,IIIs–3
Rg	Red Bluff gravelly loam	0–3%	IIIs–9
Rh	Red Bluff gravelly loam, hardpan substratum	0–3%	IIIs–9
RnA	Redding gravelly loam	0–3%	IVs–8
Rr	Riverwash	0–3%	VIIIw–4
ScD	Sehorn clay and clay loam	10–30%	IVe–5
ScE	Sehorn clay and clay loam	30–50%	VIe–5
TaA	Tehama loam	0–3%	IIs–3
Zc	Zamora clay loam	0–3%	I–1

SYMBOLS

Soils unit boundary

Note: Mapping is from Dept of Agriculture–SCS, 1967. Additional information on soil mapping units, slope classes and capability can be found in their report.

U.S. Geological Survey 7.5' topographic maps
in Reeds Creek watershed showing contour interval (C.I.)



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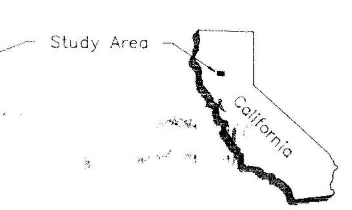

Location Map

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Sacramento Valley
Westside Tributary Watersheds
Erosion Study
Reeds Creek Soils

October 1991

LEGEND

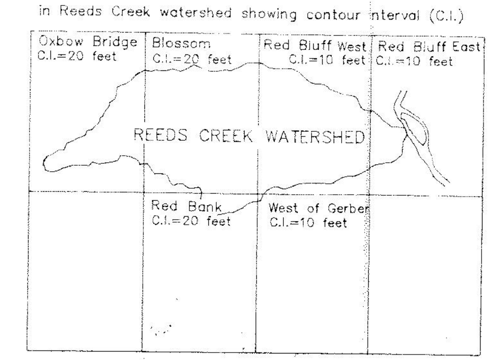
Erosion Hazard Ratings

L	LOW – Erosion resistant soils on gentle slopes. Includes soils on the Red Bluff Formation and on Quaternary Terrace Deposits. Erosion does occur along streambanks and gullies, typically by undercutting banks. Includes the rocky soils on the Great Valley Sequence and Nomlaki Tuff.
M	MODERATE – Moderately sloping upland areas of the Tehama Formation with some rill and gully erosion.
H	HIGH – Rilled and gullied areas of the Tehama Formation. The soil typically contains less clay than surrounding areas.
U	UNSTABLE AREAS – Areas with recent landslides, mostly debris slides and earthflows.

NOTE – Map is generalized based on geologic and soils mapping, aerial photo interpretation and observations of road failures and stream turbidity. Site-specific hazards must be evaluated with independent geotechnical investigations.

Hazard Boundary Contact

U.S. Geological Survey 7.5' topographic maps in Reeds Creek watershed showing contour interval (C.I.)



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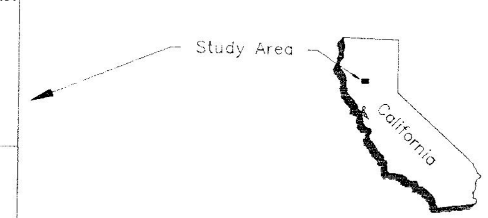

Location Map

STATE OF CALIFORNIA
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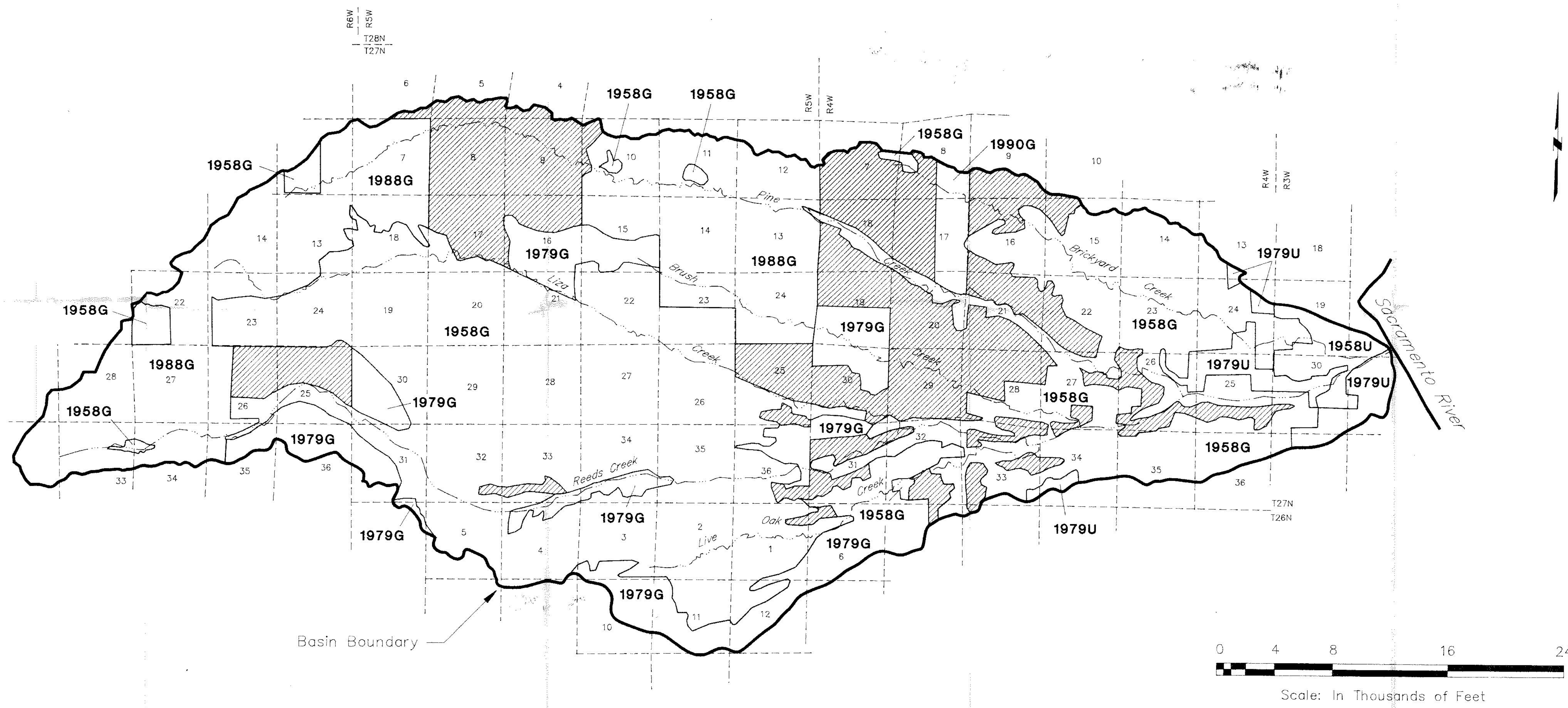
NORTHERN DISTRICT

Sacramento Valley
Westside Tributary Watersheds
Erosion Study
Reeds Creek Erosion Hazard

October 1991

PLATE 3



Legend

Land Conversion Units

1988G	Conversion unit—shows date of aerial photography on which conversion unit first appeared and type of conversion.

G = Oak Woodland to Grass, Agriculture or Savannah
U = Oak Woodland to Urban

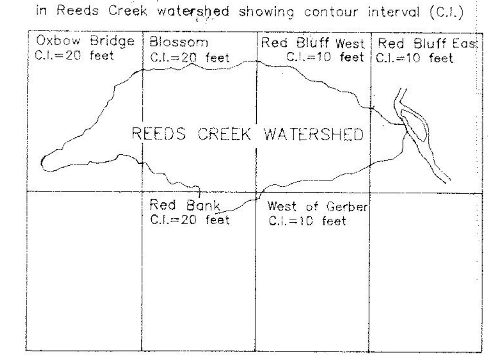
Virgin Lands

Virgin oak woodland—may contain selective cuts that cannot be identified by aerial photography.

Approximate boundary between land conversion units.

Note: 1) Vegetation data interpreted from aerial photos. Boundaries are approximate.
2) Aerial photos were flown in 1958, 1979, 1988 and 1990.

U.S., Geological Survey 7.5' topographic maps in Reeds Creek watershed showing contour interval (C.I.)



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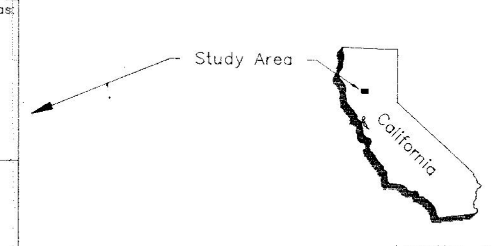

Location Map

STATE OF CALIFORNIA
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NORTHERN DISTRICT

Sacramento Valley
Westside Tributary Watersheds
Erosion Study
Reeds Creek Land Conversion

October 1991

CONVERSION FACTORS

Quantity	To Convert from Metric Unit	To Customary Unit	Multiply Metric Unit By	To Convert to Metric Unit Multiply Customary Unit By
Length	millimetres (mm)	inches (in)	0.03937	25.4
	centimetres (cm) for snow depth	inches (in)	0.3937	2.54
	metres (m)	feet (ft)	3.2808	0.3048
	kilometres (km)	miles (mi)	0.62139	1.6093
Area	square millimetres (mm^2)	square inches (in^2)	0.00155	645.16
	square metres (m^2)	square feet (ft^2)	10.764	0.092903
	hectares (ha)	acres (ac)	2.4710	0.40469
	square kilometres (km^2)	square miles (mi^2)	0.3861	2.590
Volume	litres (L)	gallons (gal)	0.26417	3.7854
	megalitres	million gallons (10^6 gal)	0.26417	3.7854
	cubic metres (m^3)	cubic feet (ft^3)	35.315	0.028317
	cubic metres (m^3)	cubic yards (yd^3)	1.308	0.76455
	cubic dekametres (dam^3)	acre-feet (ac-ft)	0.8107	1.2335
Flow	cubic metres per second (m^3/s)	cubic feet per second (ft^3/s)	35.315	0.028317
	litres per minute (L/min)	gallons per minute (gal/min)	0.26417	3.7854
	litres per day (L/day)	gallons per day (gal/day)	0.26417	3.7854
	megalitres per day (ML/day)	million gallons per day (mgd)	0.26417	3.7854
	cubic dekametres per day (dam^3/day)	acre-feet per day (ac-ft/day)	0.8107	1.2335
Mass	kilograms (kg)	pounds (lb)	2.2046	0.45359
	megagrams (Mg)	tons (short, 2,000 lb)	1.1023	0.90718
Velocity	metres per second (m/s)	feet per second (ft/s)	3.2808	0.3048
Power	kilowatts (kW)	horsepower (hp)	1.3405	0.746
Pressure	kilopascals (kPa)	pounds per square inch (psi)	0.14505	6.8948
	kilopascals (kPa)	feet head of water	0.33456	2.989
Specific Capacity	litres per minute per metre drawdown	gallons per minute per foot drawdown	0.08052	12.419
Concentration	milligrams per litre (mg/L)	parts per million (ppm)	1.0	1.0
Electrical Conductivity	microsiemens per centimetre ($\mu S/cm$)	micromhos per centimetre	1.0	1.0
Temperature	degrees Celsius (°C)	degrees Fahrenheit (°F)	$(1.8 \times °C)+32$	$(°F-32)/1.8$